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TOPOGRAPHIC MAPPING OF BRAIN ACTIVITY (U)

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This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

The voluntary informed consent of the subjects used in this research was obtained as required by Air Force Regulation 169-3.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

CHARLES BATES, JR.
Director, Human Engineering Division
Armstrong Aerospace Medical Research Laboratory

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The general purpose of this research was to relate topographical mapping of brain electrical activity to performance on a task having different levels of cognitive demand. Data were collected from twelve subjects using the Sternberg memory search task with memory set sizes of 1, 4, and 6 letters. Evoked potentials (EPs) were collected from 19 electrode sites and topographic brain maps were made from these data. Data were analyzed from the first and tenth experimental session with the memory task. The overall results indicate that brain topography is a potentially powerful technique for relating brain functions to performance on tasks with varying cognitive demands. The present results confirm past research results but also clearly indicated relationships between brain functions and performance on this task that had not previously been shown. A negative EP component at 200 ms (N200) after the presentation of the stimulus was related to response set performance (positive vs negative responses) primarily in the left hemisphere and more specifically in areas of the left temporal lobe often involved in memory and/or speech

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reception and articulation. Further, as memory set increased, reaction times increased and the latency of a late positive component of the EP also increased while the amplitude of this component decreased with the increased processing load. Reaction times were shorter for trial 10 when compared with trial 1 and the N200 latencies were significantly shorter in the right anterior cortical areas. Limited analysis of data from two subsets of the subjects was also performed.

SUMMARY

The general purpose of this research was to relate topographical mapping of brain electrical activity to performance on several tasks with different cognitive demands. A total of 35 subjects were studied. Fifteen subjects participated in a linguistic cognitive task. Eight subjects participated in exploratory studies of the Sternberg memory task. Based on these exploratory studies, twelve subjects participated in an experiment in which event related cortical potentials were recorded while they performed the Sternberg task. The overall results indicate that brain topography is a potentially powerful technique for relating brain functions to performance on tasks with varying cognitive demands. The present results with the Sternberg task, for example, not only confirmed past research results but also clearly indicated relationships between brain functions and performance on this task that had not previously been shown. One example was that a negative event related potential component (ERP) at 200 ms after the presentation of the stimulus was related to response set performance (positive vs. negative responses) primarily in the left hemisphere and more specifically in areas of the left temporal lobe often involved in memory and/or speech reception and articulation. These and other results are discussed in the report. One problem with topographic analyses, as noted in the report, is the possibility of being overwhelmed with data. However, having completed this research, it will be easier to better focus on appropriate analyses in the future and to not generate the amount of data that was necessary to learn about the technique in this research.

c. ERP amplitudes

(1) Super averages..... 50

(2) Topographical analyses..... 50

d. ERP topography: summary..... 55

4. Comparisons of ERP topography among subjects with fast and slow reaction times

a. Overview..... 59

b. RT data for Group I (Fast RTs) vs. Group 2 (slow RTs)..... 60

c. Super average differences..... 63

d. ERP topography differences between Group I and Group 2..... 64

5. Psychometric data..... 68

References..... 71

Appendix: Psycholinguistic Experiment Summary... 76

LIST OF FIGURES

Figures		Page
1	Reaction times related to Trials, Response Set, and Memory Set Size	28
2	Superaverages recorded at Pz related to Response Set, Trials, and Memory Set Size (n=9).....	32
3a	Superaverages recorded at Cz related to Response Set, Trials, and Memory Set Size (n=9)	33
3b	Superaverages recorded at Fz related to Response Set, Trials, and Memory Set Size (n=9)	34
4	Superaverage Topography: Memory Set Size 1 ...	37
5	Superaverage Topography: Memory Set Size 4 ...	38
6	Superaverage Topography: Memory Set Size 6 ...	39
7	N200 latency related to Trial Effects at each electrode site	40
8	N200 latency effects related to Trial Effects: Topographical map of significant differences in t-ratios among electrodes	41
9	N200 latency effects related to Positive and Negative Response Sets at each electrode site	44
10	N200 latency effects related to Positive and Negative Response Sets: Topographical map of significant differences in t-ratios among electrodes	45
11	N200 latency effects related to Memory Set Size at each electrode	46
12	LPC latencies related to Response Set at each electrode site	47
13	LPC latencies related to Memory Set Size at each electrode site	48

14 LPC latencies related to Memory Set Size 1 versus Memory Set Size 4: Topographical maps of significant differences in t-ratio among electrodes 49

15 N200 amplitude related to Memory Set Size, Response Set, and Trial at each electrode site 53

16 N200 amplitude related to Response Set: Topographic map of t-ratios for average amplitude differences 54

17 LPC average amplitude related to Memory Set 4 versus Memory Set 6: A topographic map of t-ratios for differences at each electrode site 56

18 RT comparisons between Group 1 and Group 2 for Trial 1 61

19 RT comparisons between Group 1 and Group 2 for Trial 10 62

20 Group 1 Data: Memory Set 1, Positive Set, Trial 1 66

21 Group 2 Data: Memory Set 1, Positive Set, Trial 1 67

I. Purpose

The general purpose of this research was to use topographical mapping to study the relationships of brain electrical activity to performance on several tasks with different cognitive demands. More specifically, the questions to be answered were: (1) do topographical analyses provide information about brain functions during the performance of cognitive tasks that is not available using the more traditional analytic procedures; stated another way, does topographical mapping of brain electrical activity provide new information and a more efficient way of analyzing brain electrical activity; (2) do brain functions differ when performing a memory task with different memory loads and different response sets; (3) what differences in brain functions, if any, occur in the process of rehearsing a memory task; (4) are there differences in laterality of brain functions while subjects perform a match/no-match linguistic task. Thus, the research was designed to evaluate topographical mapping of brain electrical activity as a technique by focusing on the description of timing activity during the learning phases of a cognitive task.

II. Overview: Applications and Focus

The memory task used in this research is part of the Criterion Task Set Battery, (CTS) V1.0 developed as part of a research program supported by the Aerospace Medical Laboratory, Wright-Patterson Air Force Base (Shingledecker, 1984). The match/no-match linguistic task that was used is similar to the CTS linguistic processing task (Shingledecker, 1984). The linguistic task which we used was already available in our laboratory and was used to save start-up time.

As the research progressed, it was obvious that it was not feasible to study both the memory and linguistic tasks in depth during the time allotted for this research. The amount of data generated to produce the topographical maps (topomaps) was extensive. It was decided to concentrate on the memory task. After preliminary studies, we did not study further the linguistic task. We will submit the data which were collected using the linguistic task. As noted, the main emphasis in this report will be on the memory task.

In addition to analyzing the memory data for the entire group, we made a comparison of the ERP topomaps between the fastest and slowest subjects in terms of reaction times. Except for one subject, very few errors were made and practice did not have a significant effect on the error rate. Significant differences in topomaps were obtained between the faster and slower subjects. This is an important finding since all subjects

were at least in the superior range of intelligence. These data indicate that rate of information processing varies among subjects with high levels of intelligence.

Selected personality data also were obtained. As has been noted recently, there are theoretical reasons for considering personality and intelligence measures as complimentary (Barratt, 1985; Robinson, 1985). For example, impulsiveness has been studied as both a personality trait and as a cognitive style. The common ground to both intelligence and personality is information processing.

The results of this research have several potential applications. In selecting personnel for specific missions where speed of information processing is important, the biologically based measures of individual differences in cognition that were uncovered in this research may become useful predictors. A large sample would have to be studied to arrive at norms. Also, the measurement procedures should be made more efficient. The differences which we observed, however, were not only statistically significant but also of a practical consequence.

With larger populations, the personality and intelligence test data could be combined with the biological measures as predictors of performance in everyday tasks similar to the tasks used in this research. There is enough unique variance in the biological measures to make them potentially useful predictors in a multivariate formula.

III. Background

1. Overview

This project involves several lines of research that have merged in the last two decades into *cognitive psychophysiology*. An indepth background of each area will not be presented since there are excellent reviews in the literature. However, a few general comments will be presented since the interpretation of data always hinges to some extent upon underlying rationale. Within our own research, we use a general systems model to synthesize research data (Barratt, 1985). This approach will be evident to a limited extent in our interpretation of the current data. In contrast to more traditional data analyses, the systems approach places a different interpretation on "cause and effect" relationships (Kenny, 1979; Sutherland, 1973; Popper, 1959). Topographic analyses of data are best interpreted within a systems model.

Brief background overviews of cognition, cognitive psychophysiology, and topography will be presented below.

2. Cognition

The study of cognition has waxed and waned in psychology (Barratt, 1985). With the advent of logical positivism and behaviorism in the first half of the century, introspection and cognition in general were not popular topics for research. In the 1950's and 1960's, this trend had started to reverse itself

and there developed what many have referred to as a "cognitive revolution" or the "information processing revolution." (Simon, 1979). Stages of information processing were hypothesized within a wide assortment of models. The plethora of models has resulted in confusion since cognition or cognitive processes are always inferential and as Oden (1987) recently noted, "Thinking, broadly defined, is nearly all of psychology; narrowly defined it seems to be none of it."

The two tasks used in this research are cognitive tasks. The match/no-match linguistic task involves processing information to discover semantic differences. The memory task (after Sternberg, 1966) involves sensory-perceptual and letter recognition functions with different levels of memory set size. It is difficult to indicate that tasks involving cognitive processes don't overlap in brain functions with each other even though the task requirements appear different and the performance scores can be shown to be relatively independent by statistical analyses. The important point, as noted previously, is that "cognition is always inferential." To make inferences about cognitive processes on the bases of task demands and response measures results in the definition of a wide range of cognitive concepts (e.g., Schneider and Shiffrin, 1977). The present research was designed in part to search for possible biological correlates of stages of information processing. Finding biological measures that relate to different stages of

information processing would provide another empirical basis for making more meaningful inferences about the cognitive processes between the input and output stages of information processing.

3. Cognitive Psychophysiology

Event related brain potentials (ERPs) recorded from the scalp while subjects perform cognitive tasks have resulted in the identification of specific ERP components being related to specific task requirements (Donchin, Ritter, and McCallum, 1977). These components have traditionally been studied from only a few electrode sites, usually along the scalp midline. The components are usually defined within a fairly broad time frame, even though they have been labeled with a specific time period (e.g., P300 refers to a positive component at 300 ms post stimulus). This labeling has resulted in some confusion since the components rarely occur at the specified time period, especially for an individual subject. It would appear more meaningful to define the window within which peaks or components appear in each experiment rather than trying to speculate that a component occurring at 450 ms post stimulus is, for example, a P300 component. In the current research we used this approach.

The value of ERPs is primarily as a "bridging" function in our research. The ERP's obviously reflect cortical activity. The exact relationship between cortical and subcortical electrical activity is not known in most instances. However, as Katznelson (1981) has noted, "in Layer IV of the cortex, which is

the most prominent recipient of thalamic projections, no more than 5-10% of the synaptic terminals are of thalamic origin." Thus, cortico-cortico activity per se represents a significant source of information about brain functioning. ERP data can be considered a bridge between the behavioral and task requirement measurements and the more molecular measures of brain activity (e.g., neurochemical or tissue transport measures). Considering the brain as a "volume conductor," ERP's can also be a bridge between task requirements and a better delineation of the stages of information processing as reflected in brain electrical activity (Cohen and Waters, 1985; Sanquist, et al., 1980).

Cognitive psychophysiology, like all technique oriented research efforts, is most fruitful when it has a theoretical basis. Most of the research to date has been empirically focused. The current research effort was not aimed at testing a theoretically based hypothesis but was focused on better defining a specific memory task. Some recent memory theories are relevant to this research and will be alluded to in the discussion of the results. Teyler and DiScenna (1986) have developed a hippocampal memory indexing theory that hypothesizes that the hippocampus contains a spatial map (index) of neocortical areas that are activated by experiential events. They propose that a "hippocampal index" is biologically related to long-term potentiation of neural mechanisms. If one considers automatic information processing to be independent of working memory, this

model would interdigitate with Hunt and Lansman's (1986) model of attention and problem solving.

As noted previously, it is not our intent to present a comprehensive background for this research. What we mainly wanted to communicate were both the shortcomings and the potential of current cognitive psychophysiological research. An attempt to fit ERP components into a narrow empirical mold has in some ways preempted the potential value of ERPs as a bridge between behavioral data, more molecular brain processes, and cognitive theory. For example, combining ERP measurements with behavioral measures and drug interventions is a potentially very powerful approach for studying cognition. Wolkowitz, et al., (1985) proposed psychopharmacological approaches to studying cognition, especially memory. Adding ERP's makes this a powerful approach to bridging the conceptual gaps between cognitive stages and the molecular biology of the brain.

4. Topographic mapping of brain electrical activity

EEG and ERP analyses have traditionally been made from recordings at specific electrode sites. Although multiple electrode sites have been used in past research, the analyses were analyzed and displayed for individual electrodes. One of the earlier topographic displays of EEG activity used a configuration of lights whose brightness related to the amplitude of the EEG at specific electrode sites (Walter and Shipton, 1951). The question posed in the current research is "does

topography add anything to the more traditional analyses of EEG and ERP data." Tyler (1986) after listening to a series of topography papers at a meeting noted:

> I was disappointed in the clinical information. It was often narrative and not statistically or conceptually sophisticated. This reached its peak when one saw slide after slide of derived "data" from a small sample of EEGs with no meaning apparent or demonstrated by the speaker. In this instance, I felt there were more meaningful data seen in the original tracing than the derived. It became clear that there is no limit to the type and kind of secondary data that can be derived and the investigator needs some conceptual idea of what to look for to avoid drowning in a sea of numbers and graphs (P397).

This is an accurate assessment of much of the current use of topography. It is not ordinarily quantifiable and is not related to the basic neurophysiology of the cortex. In the current study, we realized how easy it is to be overwhelmed with the data. This is the main reason that we restricted the research to the memory task. We did approach the research with the idea that we could derive information from the topomaps that would be beyond that which is easily available in the more traditional electrode specific analyses. We had two specific characteristics of the topomaps that we wanted to observe: (1) the extent or area of the positive or negative fields at selected times post stimulus; we predicted that this would be significantly related to performance on the task; (2) the gradient from the most positive or negative point in a field to the periphery of the field which we predicted would relate to performance on the task. Athough we haven't quantified these

measures, they could be quantified by further development of our computer software. We planned to make a visual analysis of the records to see if these characteristics were meaningfully related to performance on the tasks. In addition to being quantifiable, these characteristics have interesting parallels in neurophysiological concepts. For example, if the hippocampus provides a spatial map for cortically stored information, would it be more efficient to have a smaller or larger cortical neuronal pool involved in the neural processing related to performing a task? Would the extent of the neuronal pool vary at different stages of information processing (e.g., in the exploratory vs. the final decision stage). Since our topography algorithm involves averaging across adjacent electrodes to estimate voltage levels between electrodes, the topomaps are a more complete analog of the data than the more traditional electrode specific analyses. However, the topomaps are still dependent upon measurements at each electrode site.

It should also be noted that topomaps can be made of the statistical analyses of the data at each electrode site. For example, the t ratios related to differences among the brain electrical activity recorded during the performance of the three memory load conditions were displayed using topomaps.

In the current research, we analyzed the data using the more traditional techniques as well as using the topomaps.

IV. Methods and Procedures

1. Overview

As noted previously, we originally intended to study two tasks in this research. It became evident that this was not feasible because of the amount of data being generated. We chose to restrict the topographic analyses to the memory task. However, we had partially completed the linguistic task research and presented the data at the Annual Meeting of the Society for Psychophysiological Research in 1986. The abstract that was submitted to SPR is appended to this report.

The memory task research went through several phases. We ran eight subjects in selected exploratory experiments. The first series of experiments were directed at getting the logistics and routine of the research in place. We had some problems getting the computer software and the response keys supplied by the Air Force to work. We ran the eight subjects to obtain exploratory data to make certain that our topography programs were working and to provide a basis for focusing on several relevant aspects of the research. This allowed us to run the final experiment with some hypotheses in mind. The remainder of this report will contain data on the final memory experiment.

2. Subjects

Twelve right-handed male students in the age range of 22 to 30 years participated in this experiment.

These were medical students and graduate students - all of whom scored in the superior range on the Slosson Intelligence Test (Slosson, 1983); their IQs ranged from 120 to 157. Of the twelve subjects, data from three subjects were not used in the final ERP analyses because of artifacts (eye blinks or alpha artifact).

3. Psychometric Tests

a. Personality Tests

(1). State Trait Personality Inventory (STPI)

This was developed by Spielberger (1979) and his colleagues and contains state-trait measures of anxiety, anger, and curiosity.

(2). Barratt Impulsiveness Scale (BIS-10)

The BIS-10 measures three forms of impulsiveness: Cognitive or making up one's mind quickly; motor or acting without thinking; non-planning or present as opposed to future orientation.

(3). Eysenck Personality Questionnaire (EPQ)

Measures extraversion, neuroticism, psychoticism, and has a validity (L) scale.

b. Ability and Cognitive Style

(1). Slosson Intelligence Test (Slosson, 1983)

This is an individually administered test of general intelligence.

(2). Spatial Orientation (Guilford and Zimmerman, 1952)

This is part of the Guilford-Zimmerman Aptitude Survey battery. It was designed to measure spatial orientation relative to the spatial location of the body of the observer. This ability was highly correlated with pilot aptitude in WWII studies (Guilford, 1947).

(3). Embedded Figures Test (Witkin, 1965)

Measures a cognitive style related to overcoming an embedding context and being able to see "parts" of a "whole" design without being unduly influenced by the wholistic characteristics of the design.

4. Memory Task

The memory task used in this experiment is part of the Criterion Task Set (CTSS) V1.0 battery of tests developed by the Air Force Aerospace Medical Research Laboratory, Wright-Patterson AFB (Shingledecker, 1984). The procedure for using these tests is described in the User's Guide for the Criterion Task Set (Acton and Crabtree, 1985). This test is a modification of the procedure developed by Sternberg (1969). Although the Sternberg task generated

much research, there have only been a limited number of studies that have recorded ERP's during the performance of the task (Gomer, et al., 1976; Marsh, 1975; Ford, et al., 1979; Adam and Collins, 1978; Roth, et al., 1977; Roth, et al., 1975; Roth, et al., 1978). Also, it is important to realize that there have been slight to moderate changes in procedures from Sternberg to the current research. In general however, the behavioral results have been consistent across experiments. The following is a description of the task and testing procedure (from Shingledecker, 1984).

Description

The CTS Memory Search Task, based on Sternberg's (1969) memory search paradigm, is a standardized task designed to place variable demands on human information processing resources dedicated to short-term memory retrieval functions. In the memory search task, a small set of items (the "memory set") is first presented to the subject for memorization. A series of test items are then presented to the subject one at a time, and the subject must respond positively if the test item was contained in the memory set, or negatively if not. Reaction time is measured from the onset of the test item to the response. The CTS version of the task is composed of three fixed demand levels produced by variations in the number of items to be memorized. Research conducted at the AFAMRL workload

laboratory has demonstrated that memory set sizes of one, four, and six items produce reliably different levels of performance and subjective workload.

Stimuli

Stimulus items in the CTS memory search task are visually presented alphabetic characters. Due to the acoustic confusability of certain letters only 17 of the 26 letters of the alphabet are used in the task (ABCEFGHIJLOQRSXYZ). Memory set items are randomly selected from the letter population, and the remaining items are used in the negative set. A new memory set is selected at the beginning of each 3-minute test period. Test items are also randomly generated with the restriction that positive and negative set items are drawn with equal probability.

Testing Procedure

Major practice effects are eliminated with seven training trials at each loading level. However, extension of training to 16 trials produces more stable performance on the memory search task. Subjects are encouraged to respond as rapidly and accurately as possible. In all conditions, the task is subject paced with a deadline, allowing the subjects to pace themselves within experimenter determined time constraints. Maximum acceptable reaction times in the training mode is 15 seconds for all

memory set sizes. If the subject does not respond within 15 seconds after the onset of a test item, the next item is automatically presented. In the testing mode, reaction time deadlines are reduced: 1.5 seconds for memory set size one, 2.0 seconds for set size four, and 2.5 seconds for set size six. Letters are approximately .5 x .7 cm and should be viewed from a distance of roughly 60 cm. Responses are entered on appropriately labeled keys. Subjects are given feedback concerning the accuracy of their performance after each test period to ensure that an acceptable speed-accuracy trade-off is maintained (less than 5 percent error).

5. Psychophysiological Recordings

Event related potentials were recorded from 19 electrode sites within the International 10-20 system (Fz, Cz, Pz, FP1, FP2, F7, F3, F4, F8, T3, C3, C3, C4, T4, T5, P3, P4, T6, O1, O2. EOG's were recorded from two electrodes, one 2 cm. lateral and the other 2 cm. superior to the left eye. All electrodes were referenced to the nose and subjects were grounded via an electrode placed on the forehead. The EEG and EOG were digitized at a rate of once every 4 ms. for a two second interval beginning one second prior to stimulus onset. The digitized EEG and EOG were stored in the laboratory computer's hard disk for later off-line analysis. A high frequency cut-off of 15 Hz (30% attenuation) was emphasized in conjunction with a 5 sec.

time constant. All electrode impedances were required to be less than 5 K ohm.

Trials contaminated by EEG or EOG deflections exceeding 50 u V were excluded from the data analyses. For the remaining trials, positive correlations with evoked EOG activity was statistically removedfrom the single-trait evokedEEG segments prior to off-line averaging. This was done on a trial x trial basis by first computingthe correlation between the digitized amplitude measures (1 every 4 ms.) of evoked EEG activity available for a given trial and the digitized amplitude measures of that EEG segment's corresponding evoked EOG segment. If this correlation was positive, a regression line was plotted through that trials' EEG/EOG amplitude scatterplot. The regression line, along with the amplitude scatterplot around it, were then rotated so that the regression line had a slope of zero, thereby reducing the evoked EEG/EOG correlation for that trial to zero.

6. Within and between task schedules

Subjects were administered the psychometric tests during one two hour session. The only psychometric test administered during the experimental session was the STPI. The three sizes (1-4-6 letters) of memory set items were presented on each of ten trials. That is, each trial consisted of 150 responses. The task was repeated 10 times.

V. Results

1. Behavioral Data: Error Rate

The error rates for all subjects were less than 5% under all conditions. For one subject the error rate overall during the first trial was 10%. Since this was less than a chance occurrence, this subject's data were not excluded from the analyses. The error rates were not significantly different across conditions. The error rate in the study is consistent with the description of the task in the test battery manual (Shingledecker, 1984).

2. Behavioral Data: Reaction Times

The analyses of variance of reaction times reported here are for 9 subjects. These results are consistent with the analyses for 12 subjects.

Reaction times were significantly related to three conditions (Table 1 and Figure 1): (1) memory set size; reaction times incresed as the number of letters to be remembered increased; (2) response set; reactions to letters not among the memory sets (negative) were significantly slower than were the reactions to items that were among the memory sets (positive); (3) trial effects; reactions during trial 10 were significantly faster than reactions during trial 1. There were no significant interaction effects among the three main conditions. These

results are consistent with past research efforts. The trial effects in the analyses of variance were for trials 1 and 10 because these are the trials used in the ERP analyses. The increases in RT between trials 1 and 5 for selected conditions are surprising. If these variances were related to some general condition such as arousal effects, you would have expected the same effects for the one letter memory set size. There was an obvious decrease in reaction times between trial 1 and trial 10 under all conditions with the decrease being the least for the positive responses with a four letter memory set size.

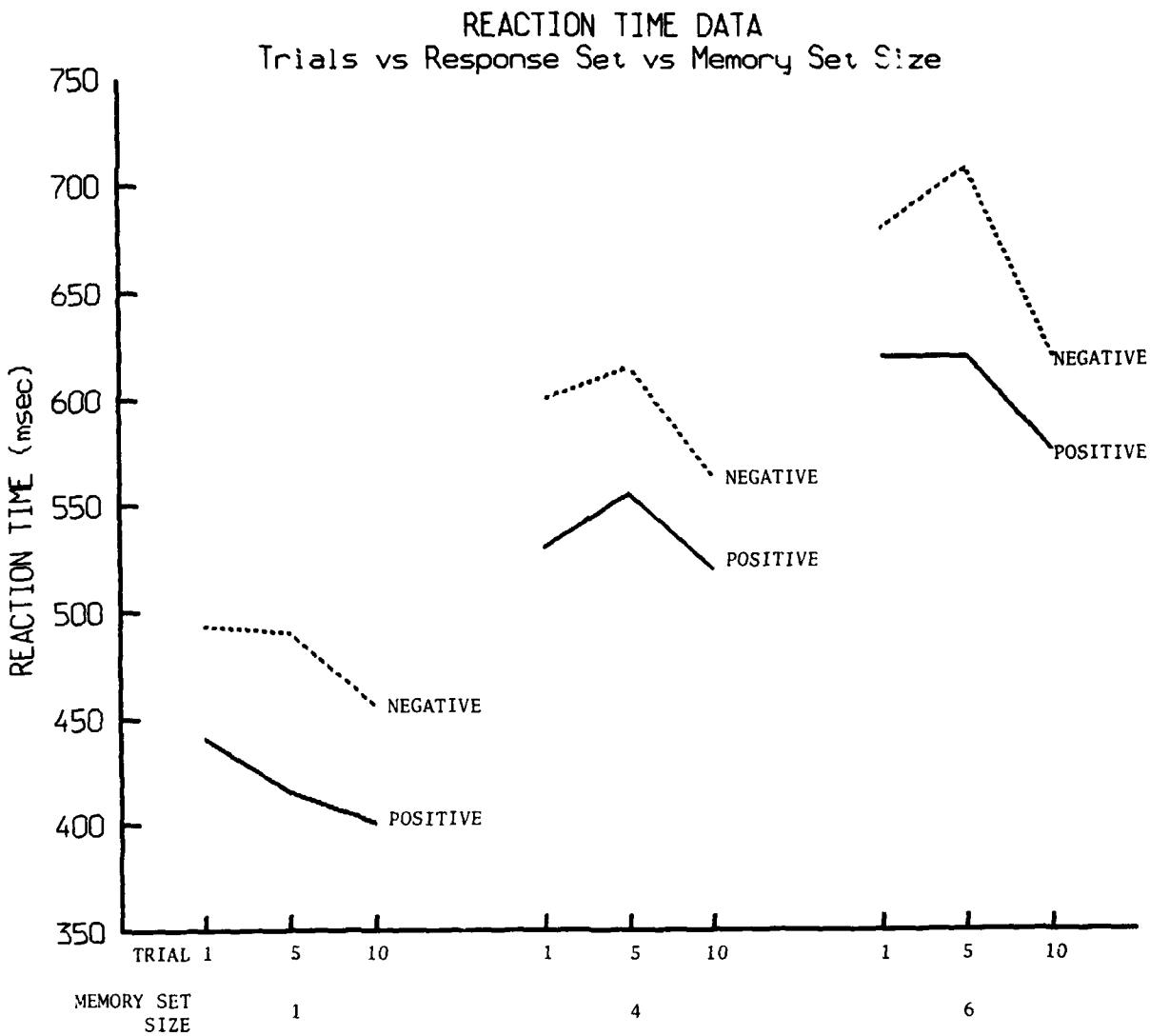


Figure 1. Reaction times related to Trials, Response Set, and Memory Set Size.

	F	P
Memory Set Size	68.2	< .0001
Response Set	48.2	< .001
Trial Effects	5.86	< .011

Table 1. Analylis of variance relating reaction times to memory set size (1, 4, 6), response set (positive, negative), and trials (1, 10).

3. ERP Analyses

a. Overview

ERP analyses were restricted to two components, N200 and the late positive component (LPC). These two components demonstrated significant differences in selected conditions in the analyses of variance. Consistent with past research, these are the two components most often present with cognitive tasks similar to the Sternberg task. The LPC is often divided into several components (e.g., P300, P300a, P300b, slow wave) but for our analyses, the super average did not warrant this separation. Further, the PCA also did not warrant separating LPC into several components.

The analyses will be presented for both the latencies and amplitudes of the ERP's under the different conditions. The more traditional analyses at specific electrode sites will be presented along with the topographic analyses.

b. ERPs: Latencies

(1). Super averages at electrode sites Cz, Pz, Fz.

As noted in the overview, only two ERP components were reasonably well defined within the time windows used for component definition. The super averages indicate that within the time windows for

N200 and LPC, clearly defined components are present for most conditions (Figures 2, 3a, 3b). Latency differences related to memory set level (1, 4, 6) as well as response set (positive vs. negaetive) are evident in the super averages.

For positive responses the latencies of the two ERP components related to memory set size 1 were shorter than for memory set sizes 4 and 6. This was evident at all three midline electrode sites and on both the first and tenth trials. There were no consistent differences between the 4 and 6 memory set sizes evident in the super averages (Figures 2, 3a, 3b). For memory set size 1, the N200 component had a shorter latency on trial 1 than on trial 10 but this was not evident for memory set sizes 4 and 6. Thus, in terms of positive responses, memory set size 1 appears to involve different brain process than set sizes 4 and 6 which appeared to be more similar.

For negative responses, the results were fairly similar in trial 10 to those obtained with positive responses except that the latencies were longer for negative responses. On trial 1, however, the difference in latencies of the ERP components at the three electrode sites was

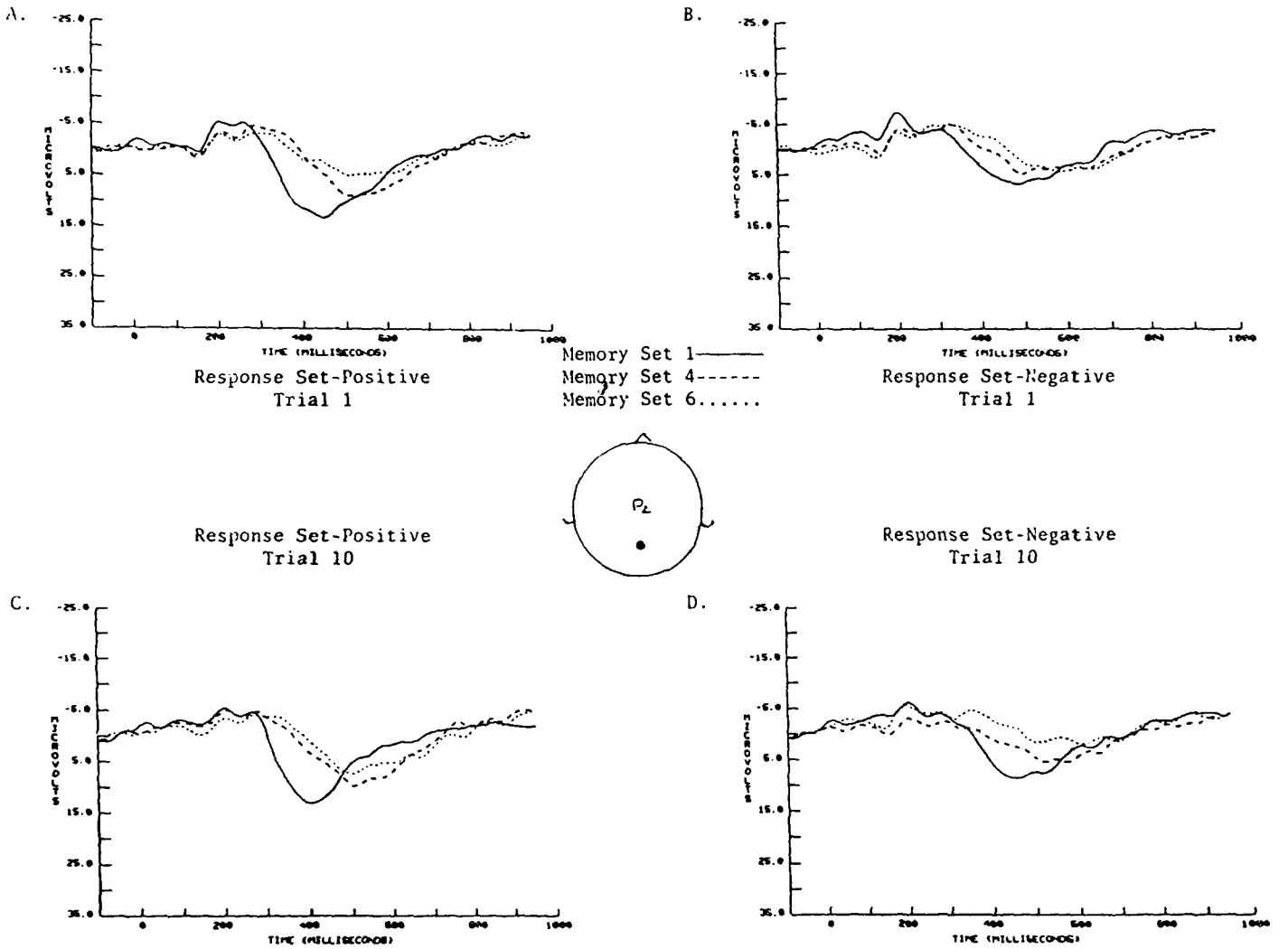


Figure 2. Superaverages recorded at Pz related to Response Set, Trials, and Memory Set Size (n=9).

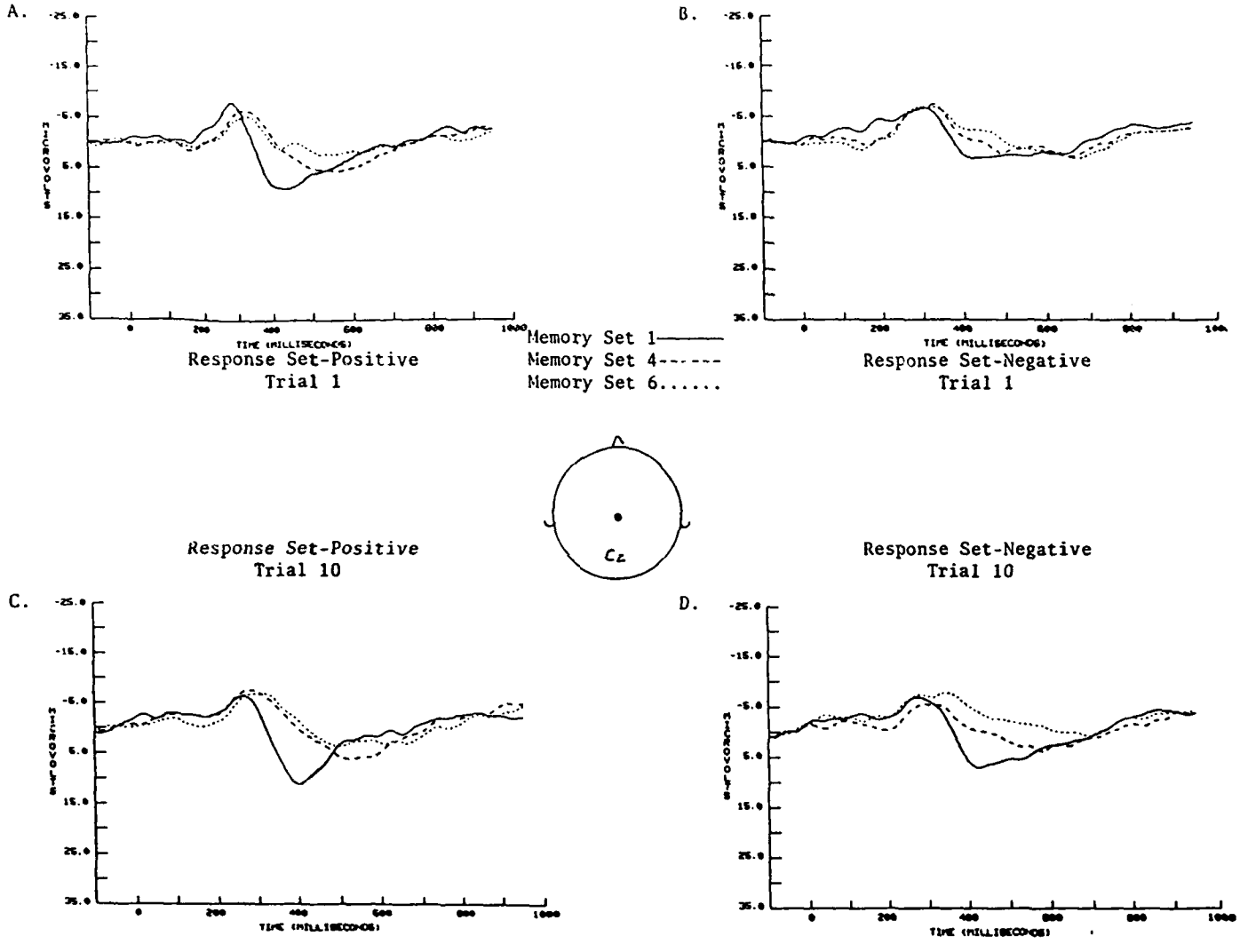


Figure 3a. Superaverages recorded at Cz related to Response Set, Trials, and Memory Set Size (n=9).

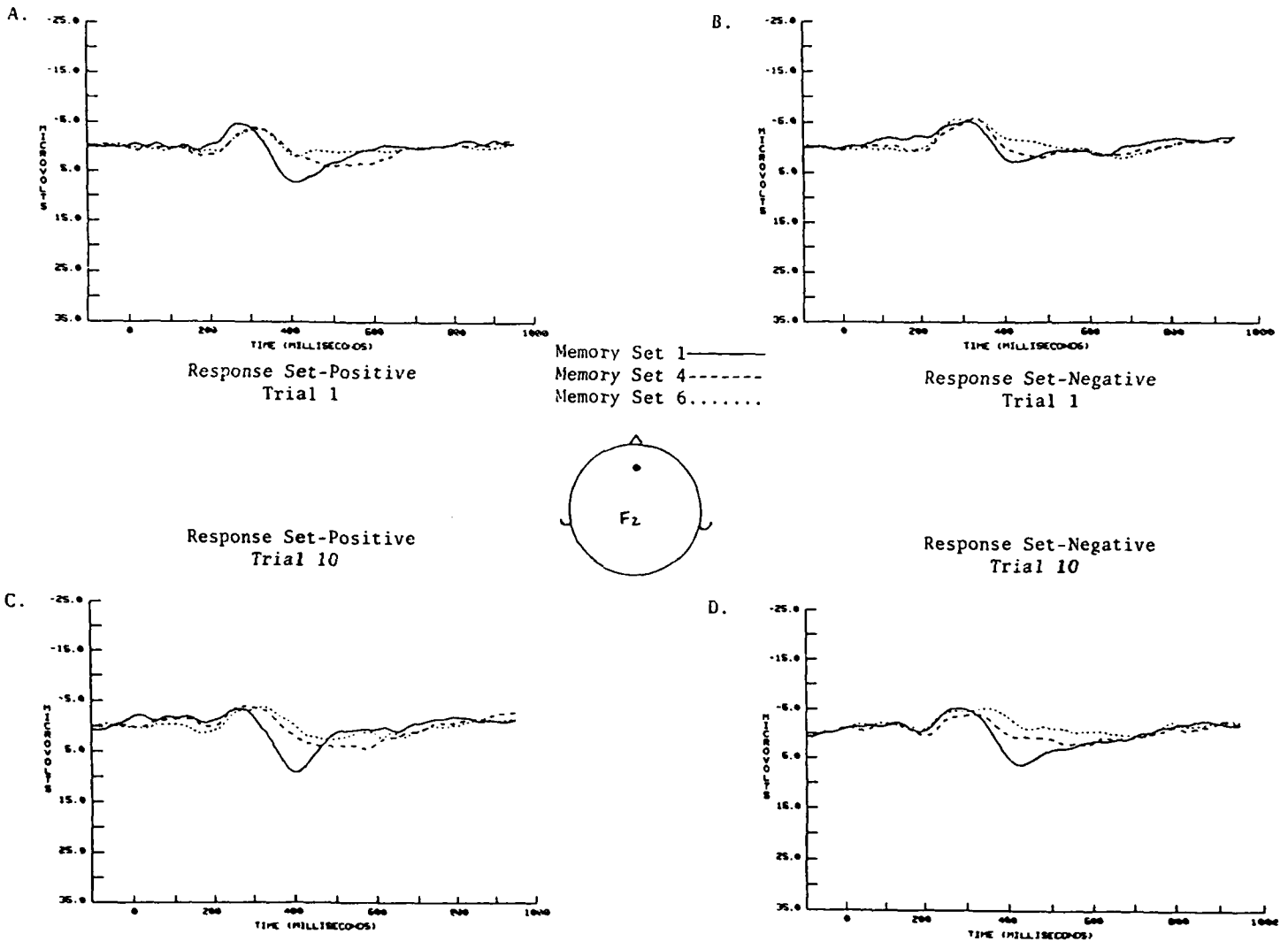


Figure 3b. Superaverages recorded at Fz related to Response Set, Trials, and Memory Set Size (n=9).

relatively consistent, suggesting that as exposure to the task and learning occurred, the differences became more obvious among the three memory set levels. Across the trials, the difference in latencies of the ERP components among all three memory set sizes was consistent with differences in the reaction time data; that is the reaction times were shorter for memory set 1 and longer for sets 4 and 6. The ERP components, especially for LPC at Cz, paralleled these latency differences (Figures 2, 3a, 3B).

These results indicate that: (1) positive and negative responses have different latencies in the ERP components; (2) during positive responses, differences in the latencies of the ERP components related to memory set size are evident on the initial learning trials; memory set size 1 differs from 4 and 6 which do not differ appreciably from each other in latencies; (3) during negative responses, the differences in the latencies of the ERP components are not evident on trial 1 but are evident on trial 10 and appear to vary with all three memory set sizes, especially at the Cz electrode site.

(2). Topographic Analyses of ERP Latencies

The analysis of variance for latency effects (Table 2) indicated significant main effects for all four conditions for N200 while only memory set size and electrode site main effects were significant for LPC. The N200 component is clearly evident in the posterior leads across all conditions in the topomaps for the three memory set sizes (Figures 4, 5, 6).

The N200 latency differences related to trial effects were significant and appear to be related primarily to right frontal electrodes (Figures 7, 8). Figure 8 is a topomap of the t ratio differences among electrode sites for trials 1 versus trial 10. A significant difference indicates trial 10 N200 latencies are shorter. A t ratio of 2.5 is scal d in the green-yellow band and is borderline significant. All colors above that band are statistically significant. As noted above, the right anterior electrode is where the more specific effects are located with regard to latencies across trials.

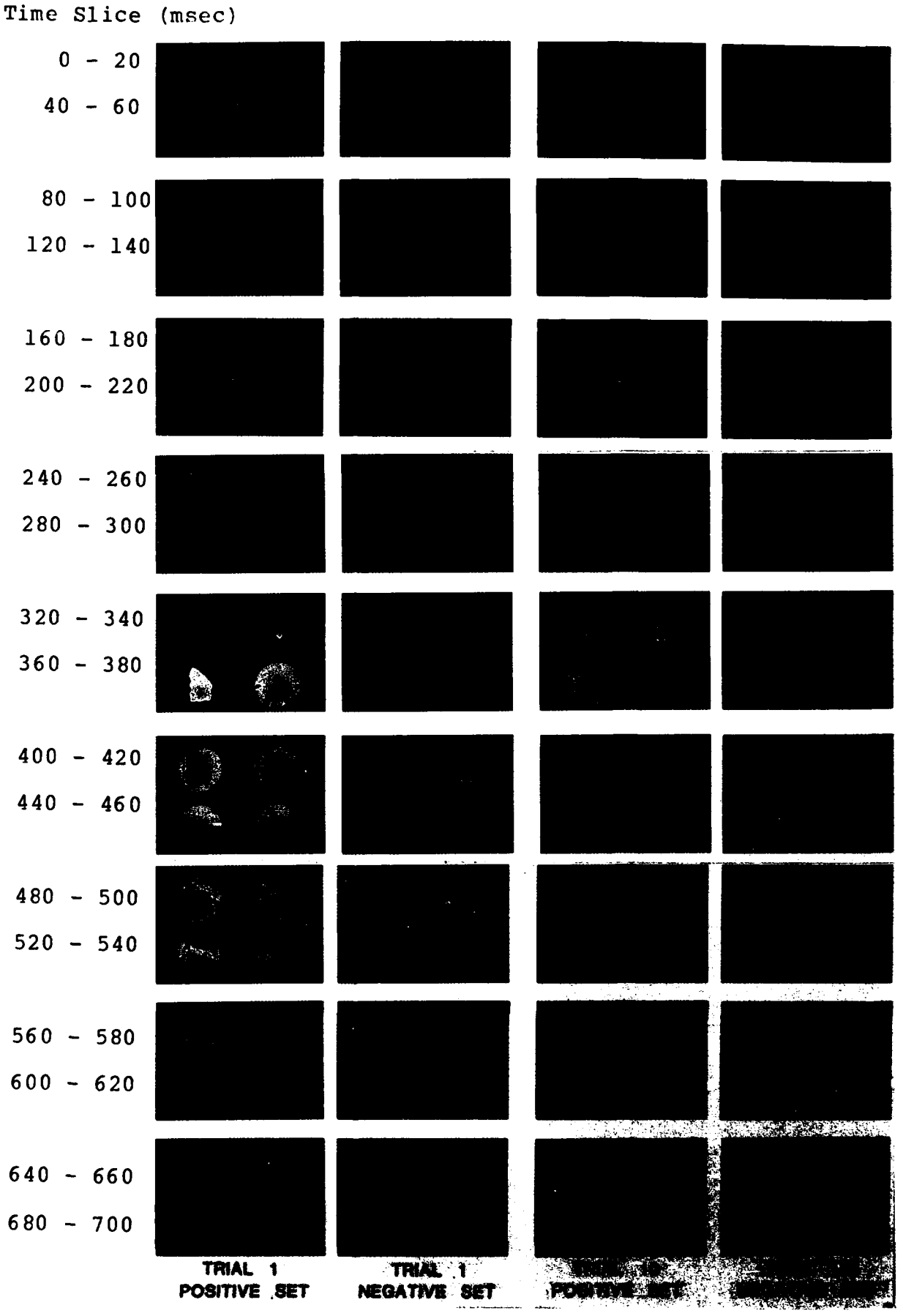


Figure 4. Superaverage Topography: Memory Set Size 1.

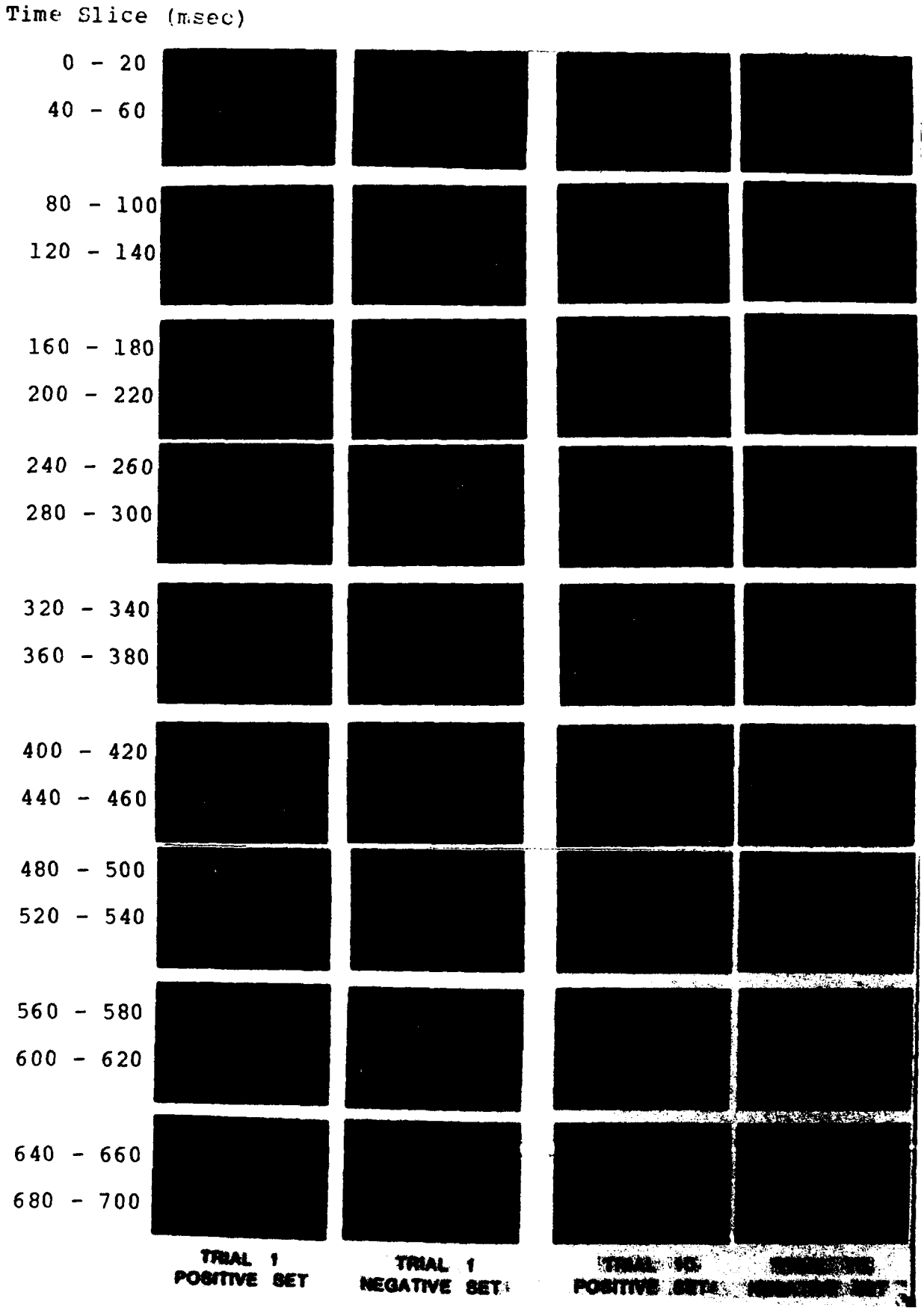


Figure 5. Superaverage Topography: Memory Set Size 4.

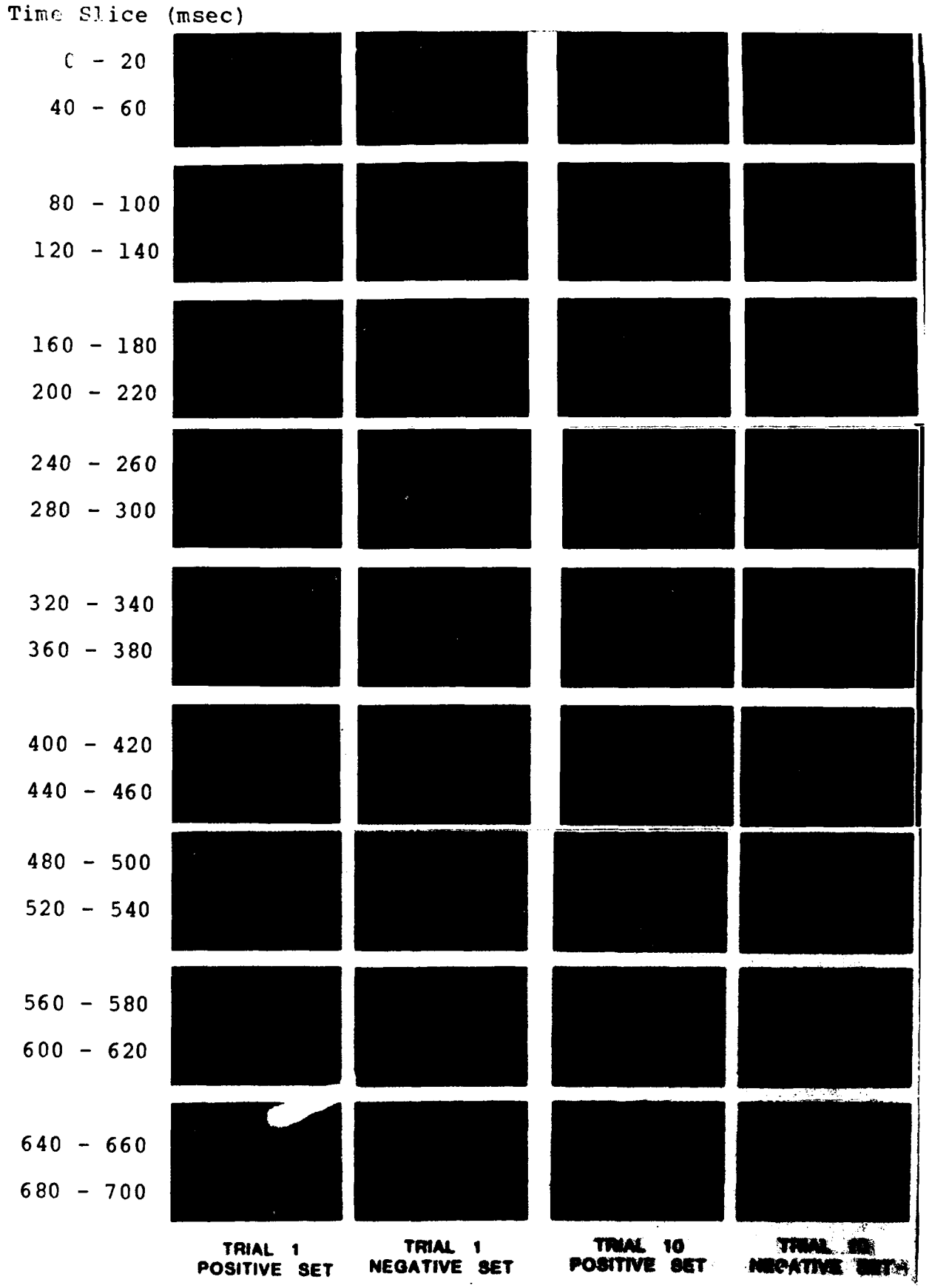


Figure 6. Superaverage Topography: Memory Set Size 6.

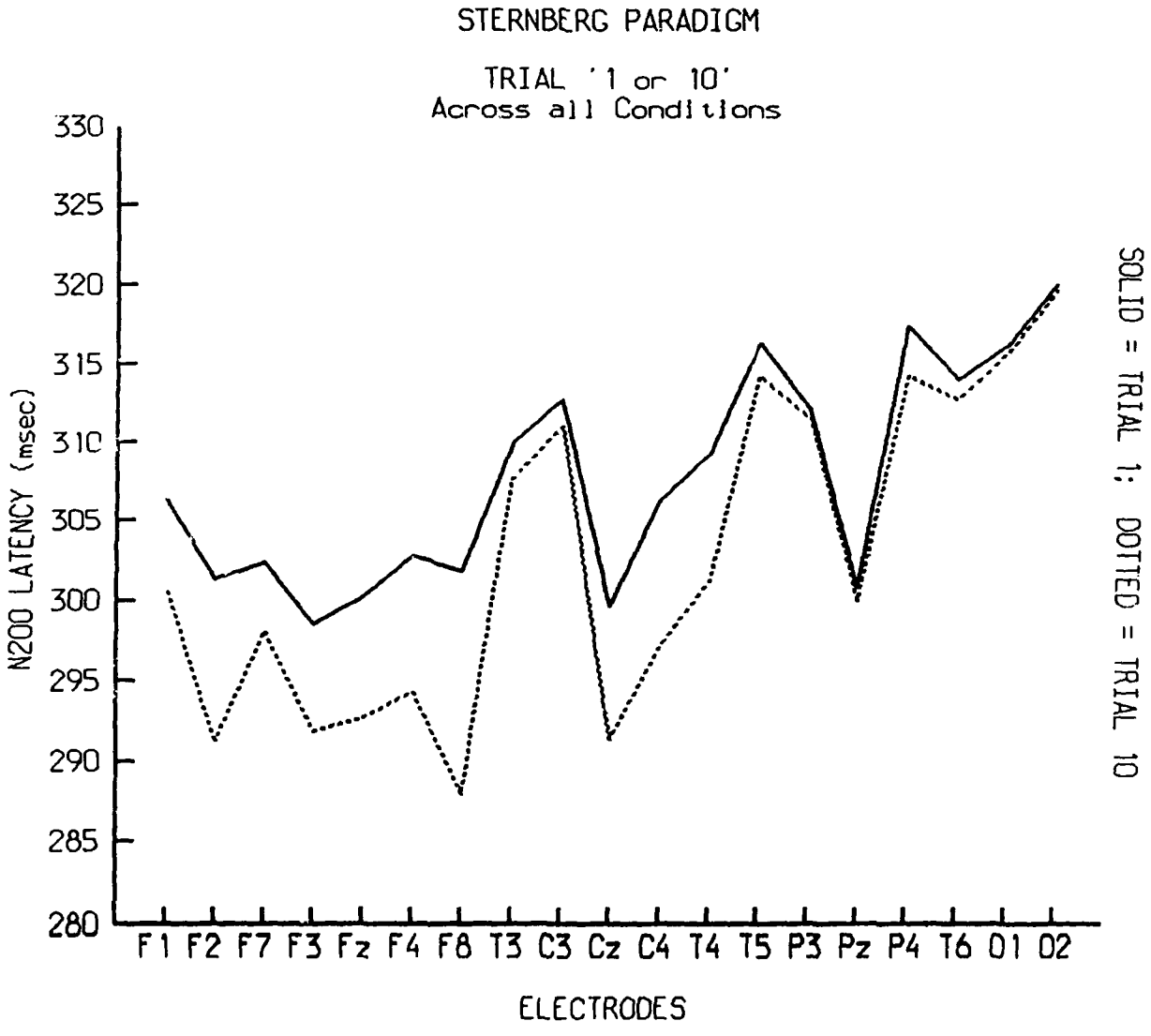


Figure 7. N200 latency related to Trial Effects at each electrode site.

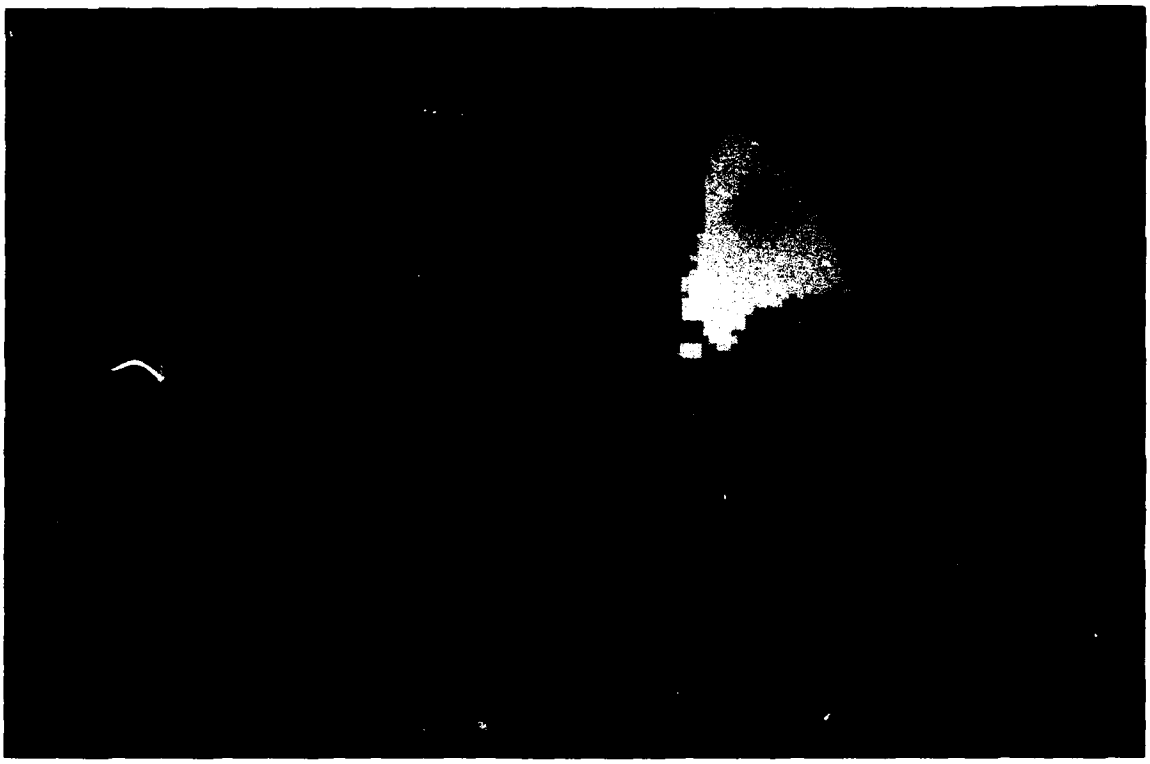


Figure 8. N200 latency effects related to Trial Effects: Topographical map of significant differences t-ratios among electordes.

	N200	LPC
Trial (1 vs. 10)	$P \leq .05$	NS
Memory Set Size (1,4,6)	$P \leq .0007$	$P \leq .0007$
Response Set (Pos. vs. Neg.)	$P \leq .001$	NS
Electrode Site (1-19)	$P < .001$	$P < .001$
Trial X Memory Set Size	NS	$P \leq .05$
Trial X Response Set	NS	NS
Trial X Electrode	$P \leq .0006$	$P \leq .04$
Memory Set Size Response Set	NS	$P \leq .01$
Memory Set Size X Electrode	NS	$P \leq .03$
Response Set X Electrode	$P \leq .01$	NS

Table 2. Latencies of ERP components related to trials, memory set size, response set, and electrode site. (Analysis of variance.)

The N200 latency effects related to positive and negative response sets were primarily related to the left hemisphere with T3 being the most significant locus (Figures 9, 10).

The N200 latency related to memory set size involved primarily differences between size 1 memory vs. sizes 4 and 6 memory sets which did not appear to differ overall except at Pz and T3 (Figure 11). As noted in Table 2, the F ratio for the main effect of N200 latency related to memory set size was significant but memory set size by electrode was not sigificantly different suggesting that the main difference was not necessarily related to specific cortical areas but was a generalized main effect ($P < .13$ of memory set size vs. electodes for N200 latencies).

The LPC latencies were not significantly related to response set (Table 2 and Figure 12). LPC latencies were significantly different among memory set sizes (Table 2 and Figure 13). As noted in Figure 14, memory set level 1 was significantly different from memory set level 4 primarily in mid-line posterior and in the mid-line areas of the left hemisphere. LPC latency differences between memory set 4 and memory set

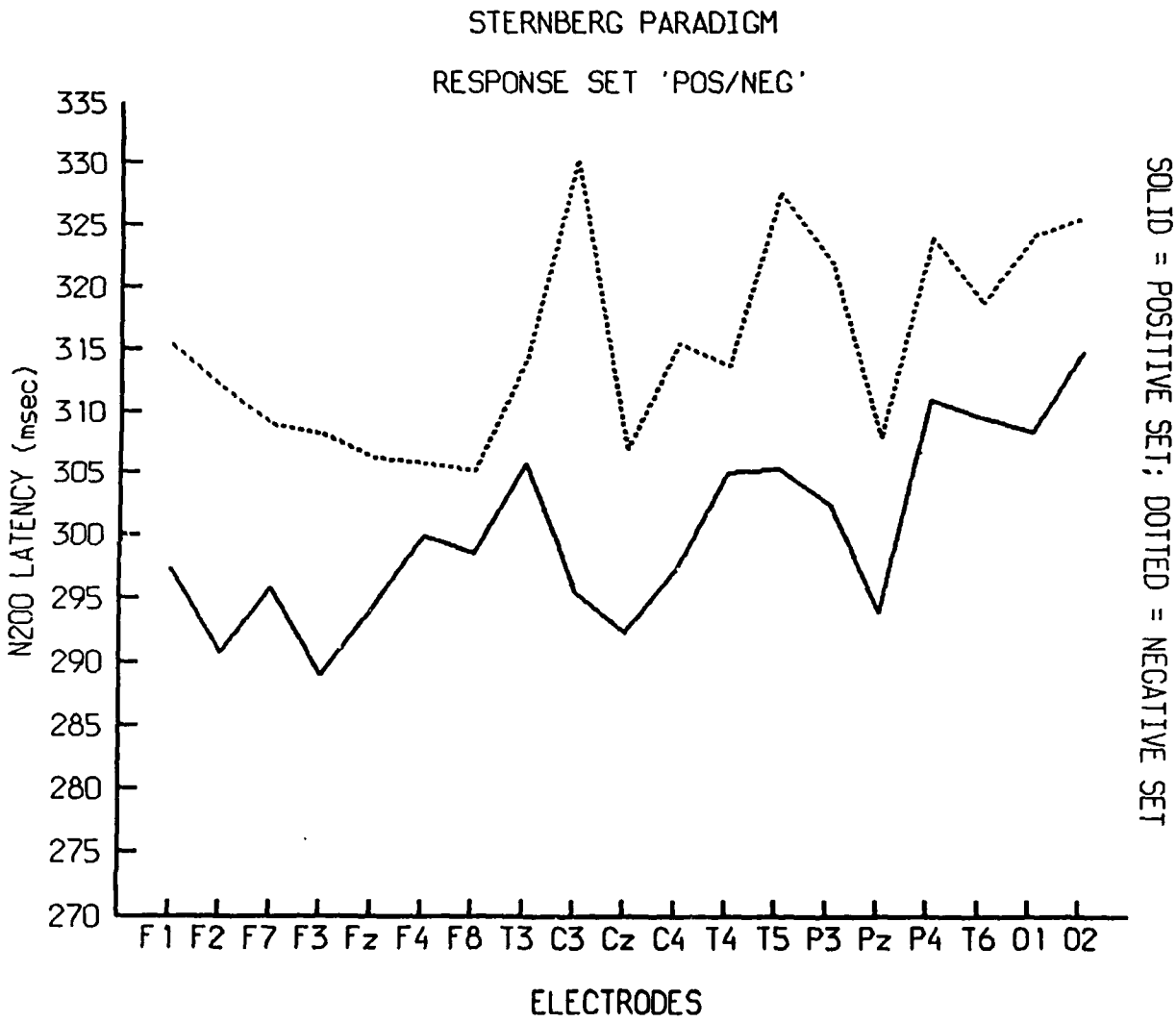


Figure 9. N200 latency effects related to Positive and Negative Response Sets at each electrode site.

Figure 10. N200 latency effects related to Positive and negative Response Sets: Topographical map of significant differences in t-ratios among electrodes.

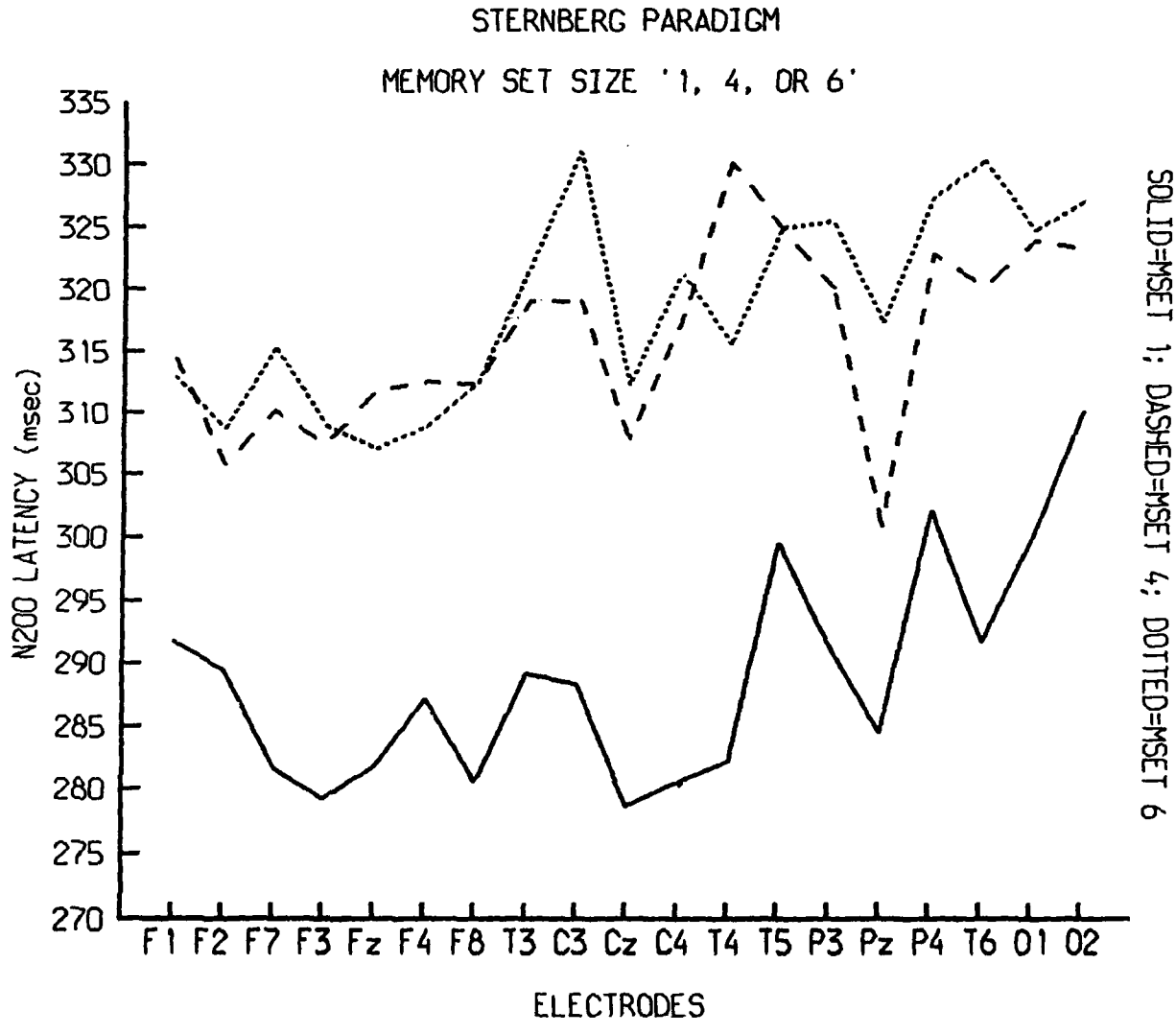


Figure 11. N200 latency effects related to Memory Set Size at each electrode.

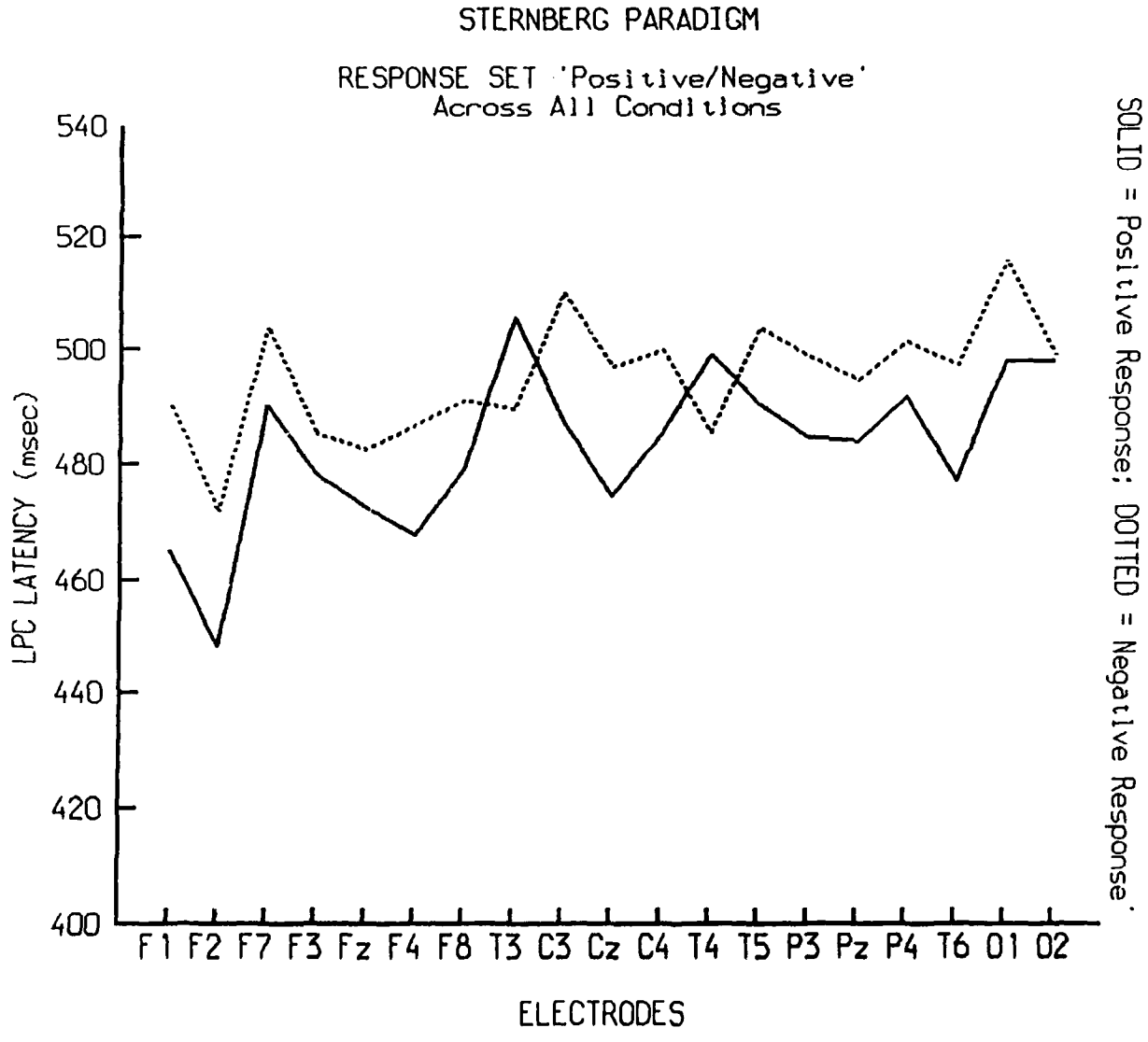


Figure 12. LPC latencies related to Response Set at each electrode site.

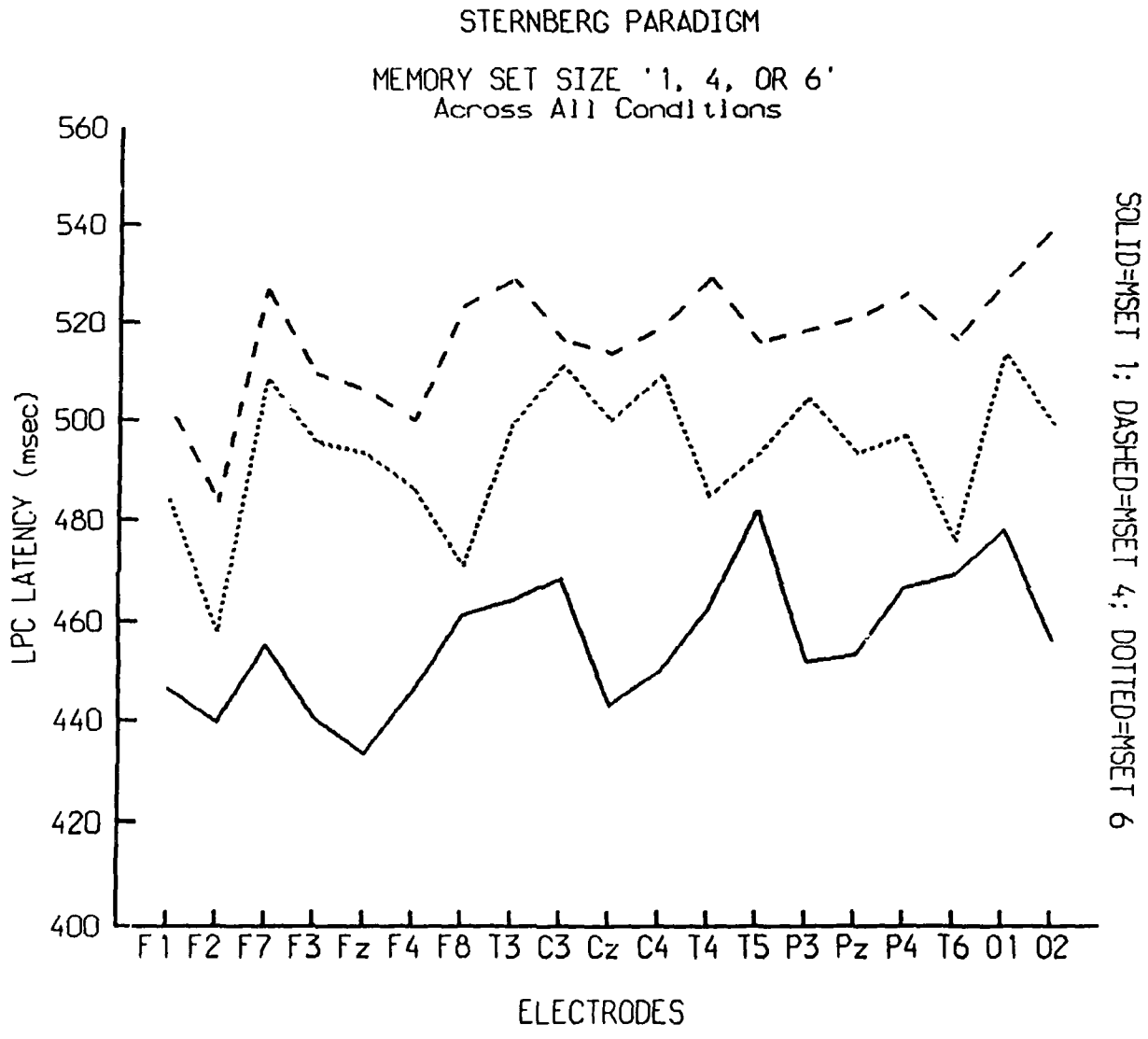


Figure 13. LPC latencies related to Memory Set Size at each electrode site.

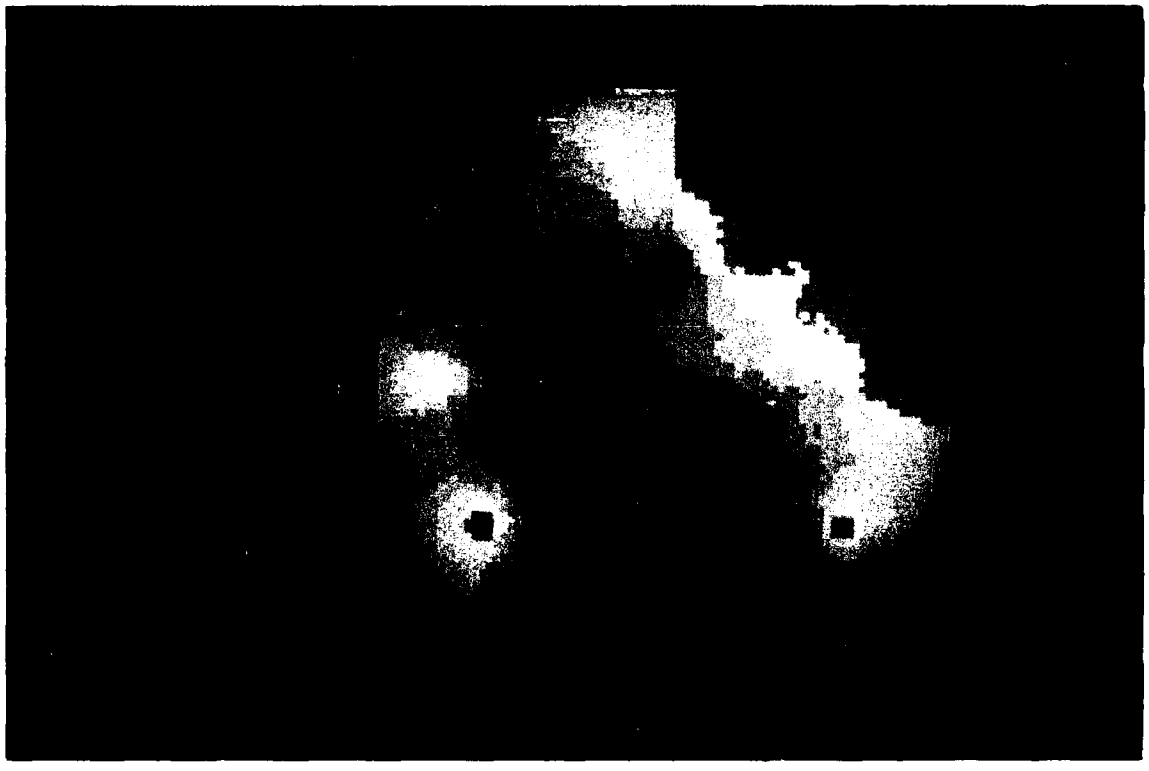


Figure 14. LPC latencies related to Memory Set Size 1 versus Memory Set Size 4: Topographical maps of significant differences in t-ratio among electrodes.

level 6 were not significant. LPC latencies were not significantly related to trial effects (Table 2).

c. ERPs: Amplitude

(1). Super averages at electrode sites Pz, Cz, Fz. (Figures 2, 3a, 3b)

No significant differences in N200 or LPC amplitudes were obtained related to trials (1 vs. 10) at the three mid-line electrode sites. Differences in amplitudes between response sets were apparent for the LPC component but not for N200. Likewise, differences in amplitude related to memory set size were obvious for the LPC component but not for N200.

(2). Topographical Analyses of ERP Amplitudes

A summary of the analyses of variance relating N200 and LPC amplitudes to the various experimental conditions is presented in Table 3. Significant main effect differences in amplitudes for both components were related to response set.

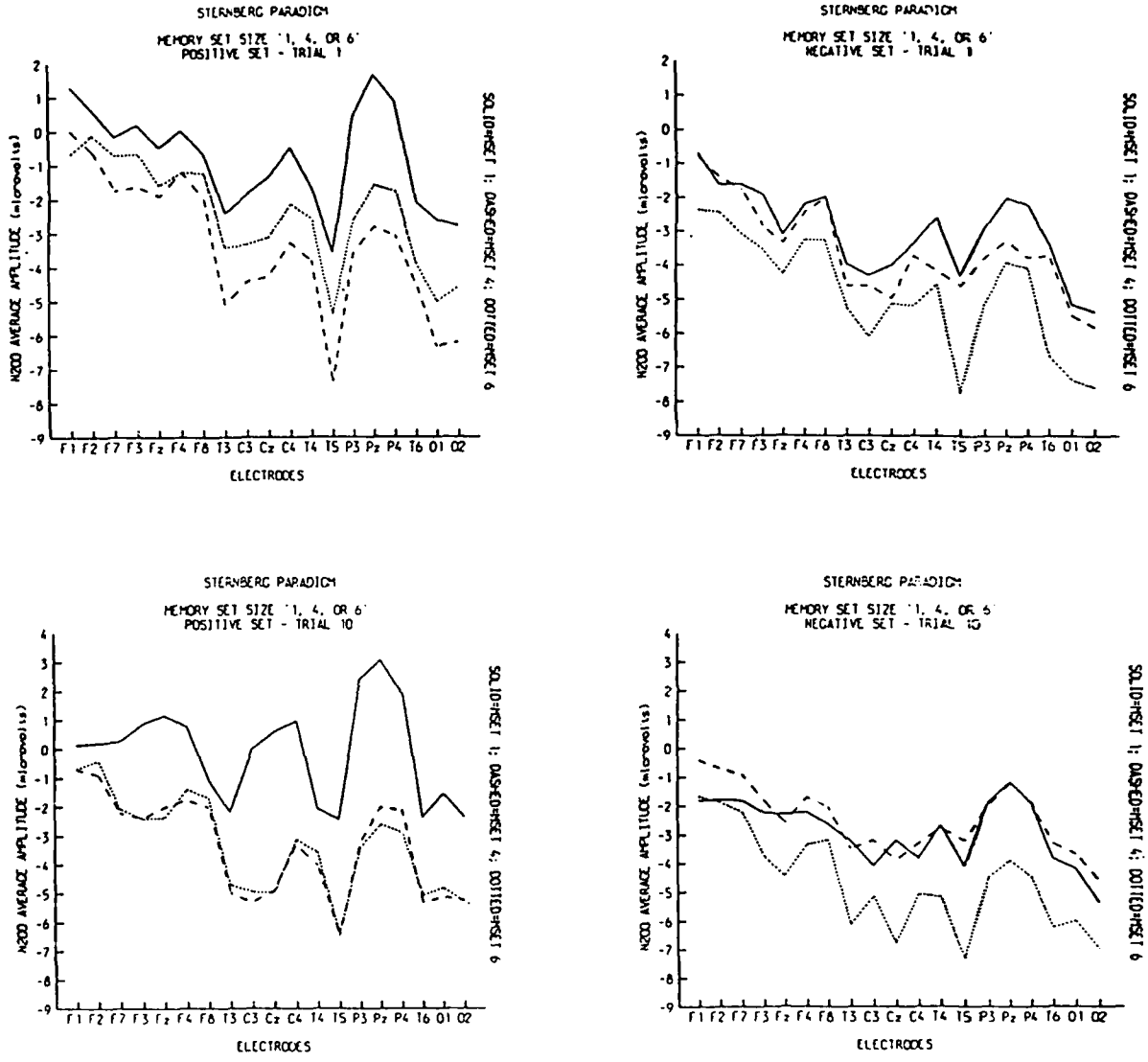
No significant trial effects were obtained for either component (Table 3). N200 average amplitudes were significantly related to response set and memory set size and response set had a

significant first order interaction effect (Table 3; Figure 15; Figure 16). As noted in Figure 16, the N200 amplitude differences were wide spread across the cortex with the main differences being in the left posterior cortex and less marked differences in the right anterior.

LPC average amplitudes were significantly different for memory set sizes and response set. The main memory set size differences were between sizes 1 and 4 vs. size 6. Memory set size 1 did not differ significantly from memory set size 4 in LPC average amplitude. Memory set size 4 was significantly different from memory set size 6 in average average amplitude with the most significant differences occurring at the frontal pole (Figure 17).

	N200	LPC
Trial (1 vs. 10)	NS	NS
Memory Set Size (1,4,6)	NS	$P \leq .01$
Response Set (Pos. vs. Neg.)	$P \leq .014$	$P \leq .005$
Electrode Site (1-19)	$P < .0001$	$P < .0001$
Trial X Memory Set Size	NS	NS
Trial X Response Set	NS	NS
Trial X Electrode	$P \leq .0002$	NS
Memory Set Size X Response Set	NS	NS
Memory Set Size X Electrode	$P \leq .0001$	$P \leq .0001$
Response Set X Electrode	$P \leq .001$	$P \leq .0001$

Table 3. Amplitudes of ERP components related to trials, memory set size, response set, and electrode site. (Analysis of variance.)



INTERACTIONS

MEMORY SET X RESPONSE SET (2, 16), F = 2.763, p .09 N.S.

MEMORY SET X RESPONSE SET X ELECTRODE (36, 288), F = 2.920, p .0000000

Figure 15. N200 amplitude related to Memory Set Size, Response Set, and Trial at each electrode site.

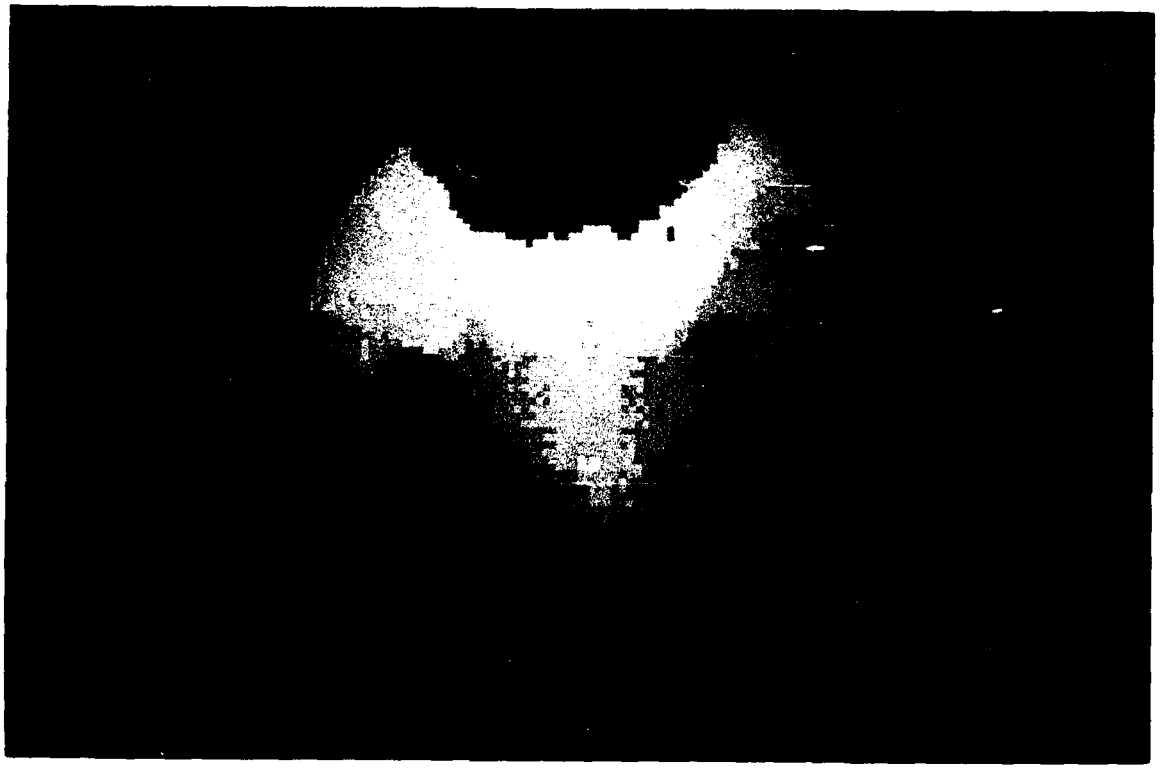


Figure 16. N200 amplitude related to Response Set: Topographic map of t-ratios for average amplitude differences.

d. ERP Topography: Summary

The ERP and behavioral data for the Sternberg task indicated:

1. Reaction times significantly decreased from trial 1 to trial 10; the only ERP data significantly related to trial effects were the N200 latencies which were significantly shorter in the right anterior cortical areas (Figure 8).
2. Reaction times increased as memory set size increased. Memory set size had a main behavioral effect relationship and with N200 latencies indicating a general effect on the cortex but the t-ratio analyses did not indicate a specific cortical locus related to this condition. The late positive component (LPC) was significantly related to memory set size. As memory set size increased, the LPC latencies increased, primarily in the posterior mid-line areas and left of the mid-line centrally (Figures 13 and 14). LPCs also had lower amplitudes as memory set size increased.
3. Reaction times were significantly shorter for the positive response set than for the negative response set. The N200 latencies were shorter for the positive responses and this effect was

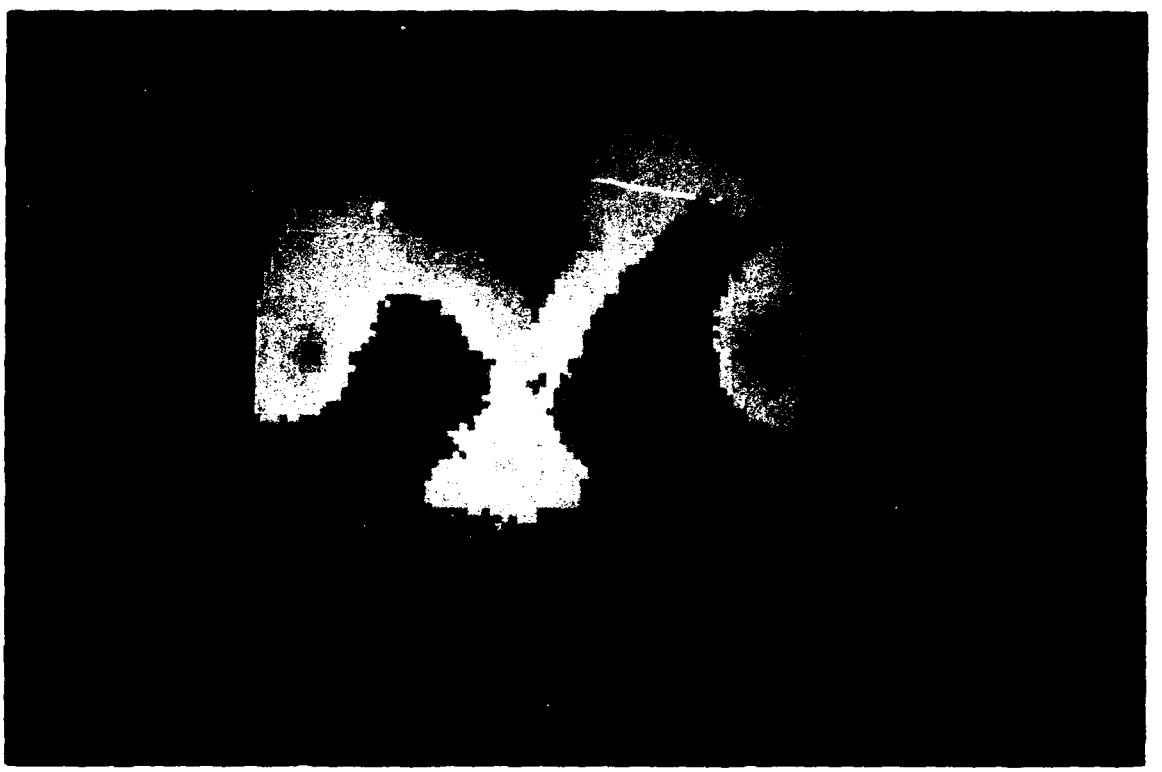


Figure 17. LPC average amplitude related to Memory Set 4 versus Memory Set 6: A topographic map of t-ratios for differences at each electrode sit.

localized on the left side of the brain (Figure 11). The LPC amplitudes were also lower for negative responses and primarily in the posterior leads.

The ERP data clearly indicate two general trends related to task demands: (1) longer latencies with increased information processing load; (2) decreased amplitudes with increased infomation processing load. Increased information processing load is defined as an increase in memory set size and/or making a negative as opposed to positive response. The higher information processing load under the higher memory set sizes is a matter of measurement. It is not as clear why positive response latencies are shorter than negative response latencies. In terms of task requirements, the stimuli appear to have the same physical requirements. There has been much recent speculation about the bases for negative responses being slower than positive responses. The current data do present an important observation about response set; namely, it appears to be a left hemisphere phenomenon in terms of N200 latencies and, more specifically, a posterior to mid-temporal lobe phenomenon

(Figure 10). These brain areas are those that are involved in memory storage. Thus, there appears to be a lateralization of functions related to response sets at the N200 ERP window. During the LPC window, the average amplitude was lower for negative than positive responses which is consistent with the above generalization.

These data provided answers to the general purposes of this research. There are differnces in cortical loci related to performing the Sternberg task. Secondly, topography does provide a technique for analyzing ERP data that makes the data anlyses more efficient. Although all of the topomap ERP data can be obtained from the more traditional analyses, the topomaps provide a more complete visual picture of the development of the ERPs. The topomap algorithm averages among electrode sites and this provides additional data that are not available in the more traditional approaches.

The topomaps provide the bases for several quantitative approaches to field analyses of the data. The data in Figures 4, 5 and 6 show marked differences in the rate of changes around positive and negative dipoles as well as differences in the

area involved at ERP peaks. The questions raised in the introduction about the possible physiological significance of these differences must be broached using quantitative techniques. Although attempts to quantify topomaps have been tried, the "rate and extent" concept has not been tried (Duffy, 1986). This concept will be illustrated in the next set of data where we analyzed groups differences in reaction times.

4. Comparison of ERP Topography Between Subjects with Fast and Slow Reaction Times (RT's)

a. Overview

These analyses are presented to illustrate: (1) an "individual differences" approach to analyzing ERP data in contrast to the "experimental psychology" approach presented above; the experimental psychology approach is a search for general laws and within this approach, individual differences represent error variance; in the approach to be outlined here, individual differences are considered to be part of the true variance; (2) to illustrate if these analyses add anything to the analyses presented earlier.

Because of the small Ns, t ratio maps and

analyses of variance were not computed. It is probable that selected differences would have been statistically significant since there are marked differences between the two groups evident in reaction times and in both the super averages and topomaps.

We also computed averages and topomaps for individual subjects but these are not represented here. The difference in topomaps for individuals was, in general, consistent with those in the fast or slow RT group of which they were a part. Subjects with fast reaction times are in Group 1 and those with slow RTs are in Group 2.

b. RT Data for Group 1 (Fast RT) vs. Group 2 (Slow RT)

The average RT's for group 1 vs. Group 2 were obviously different (Figure 18). The differences are still obvious on Trial 10 but to a slightly less degree (Figure 19). There were no overlaps in any of the RT scores between the two groups. That is, the slowest RT scores in Group 1 were faster than the fastest RT scores in Group 2.

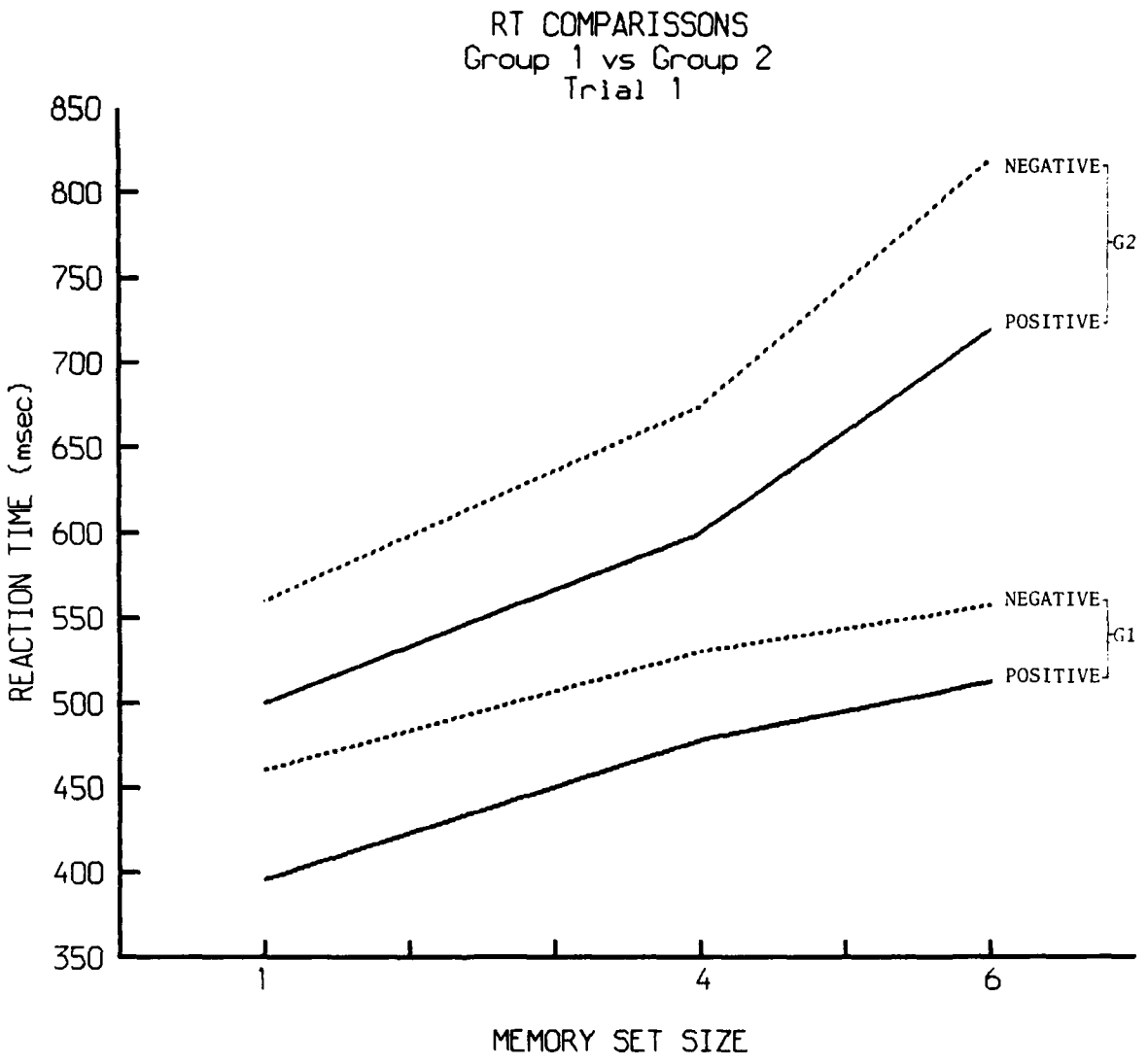


Figure 18. RT comparisons between Group 1 and Group 2 for Trial 1.

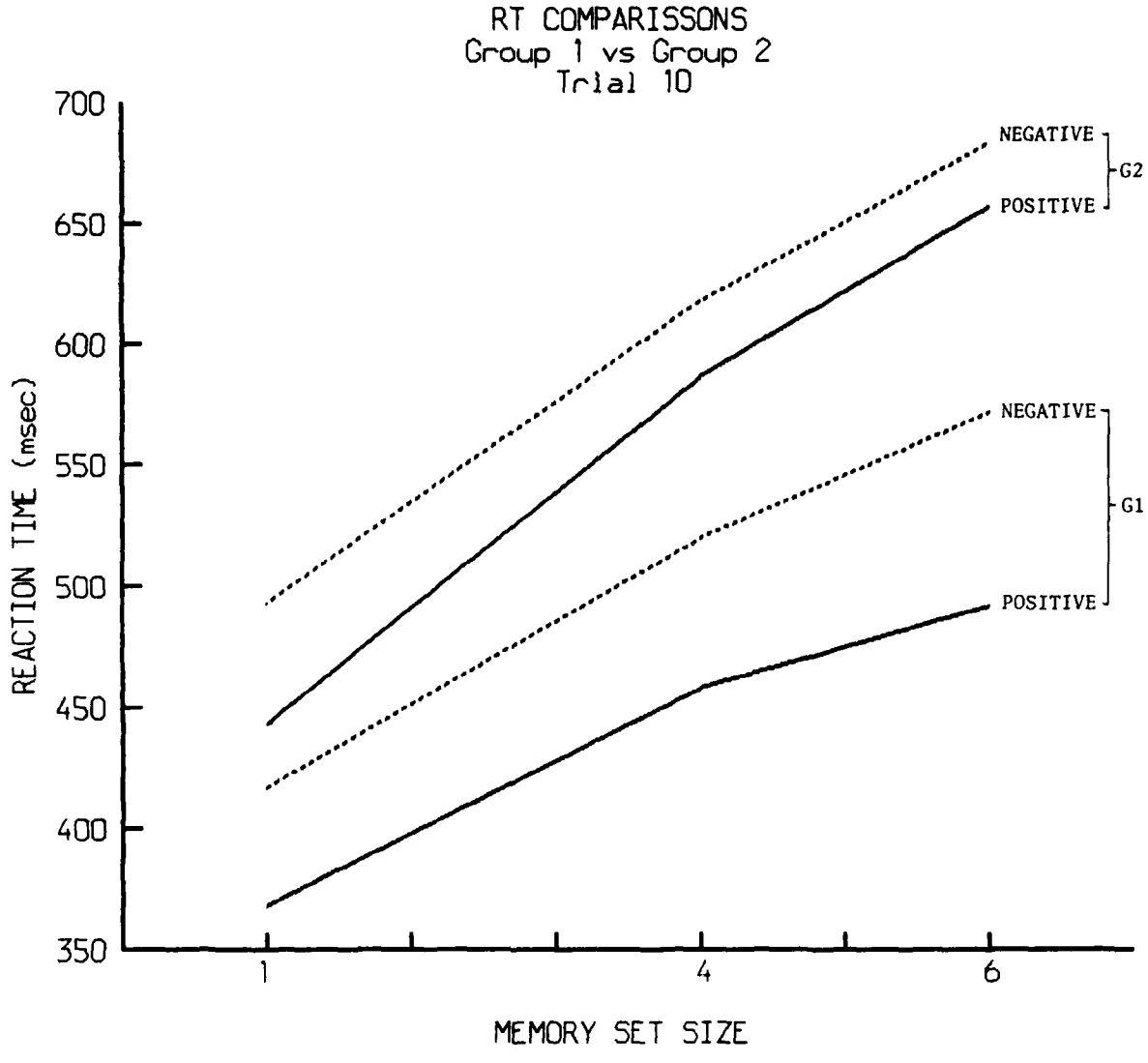


Figure 19. RT comparisons between Group 1 and Group 2 for Trial 10.

c. Super Average Differences at Pz, Cz, znd Fz Between Group 1 vs. Group 2 Related to Memory Set Size and Response Set for Trial 1.

The most obvious general differences in the super average comparisons are the more clearly defined components both in amplitude and latency for Group 1 in contrast to Group 2. This did not appear to relate to arousal level since an examination of the EEG paper tracings for each subject did not indicate arousal level differences. Beyond speculating about the bases for the Group differences the possibility of ERPs adding significantly to predictor variance for criterion task performance involving speed of cognitive responses appears to be a real possibility. Although the N's are small here, it should be remembered that these are all intellectually capable subjects who demonstrated wide differences in RT's for this task and who have what appear to be significant differences in brain functions related to the RT performance differences.

There are other more subtle analyses that can be made with these super averages. However, the main point has been illustrated: i.e., group

differences in performance and related brain functions are obvious.

d. ERP Topography Differences Between Group 1 and Group 2 Related to Memory Set Size and Response Set for Trial 1 (Figures 25 through 30)

Figures 20 and 21 contains the topomaps for Groups 1 and 2 for the conditions noted. The group difference was obtained by subtracting the electrical activity at each electrode (Group 1 minus Groups 2). Thus, a dark blue area on group difference topomaps represents a higher negative activity level for Group 1. The same interpretation applies for the orange-red areas except that these represent a more positive level of activity for Group 1.

The most obvious difference among the ERP topomaps between Group 1 and Group 2 is in the relative relationshp of N200 and LPC as memory set size increases for positive and negative response sets. For memory set size 1, a significant difference in the N200 and LPC amplitudes is evident for the positive responses (Figure 20). However, for negative responses, the differences are mainly in the N200 component (Figure 21). With memory set size 4, the N200

group differences are still obvious, but the LPC component differences for both positive and negative responses are negligble. This same pattern follows for memory set size 6. Further, as memory set size increases, differences in the sites of the change shift from a more posterior bilateral site to a more central and/or left hemisphere site. Thus, it appears that the earlier ERP at N200 relates more to efficient performance of this task in terms of RT differences than does the later LPC component. There is also a shift in the differences in the cortical sites of the N200 as information processing load is increased. Again, there are many subtle differences in the group topomaps that warrant further study. Our goal here has been to

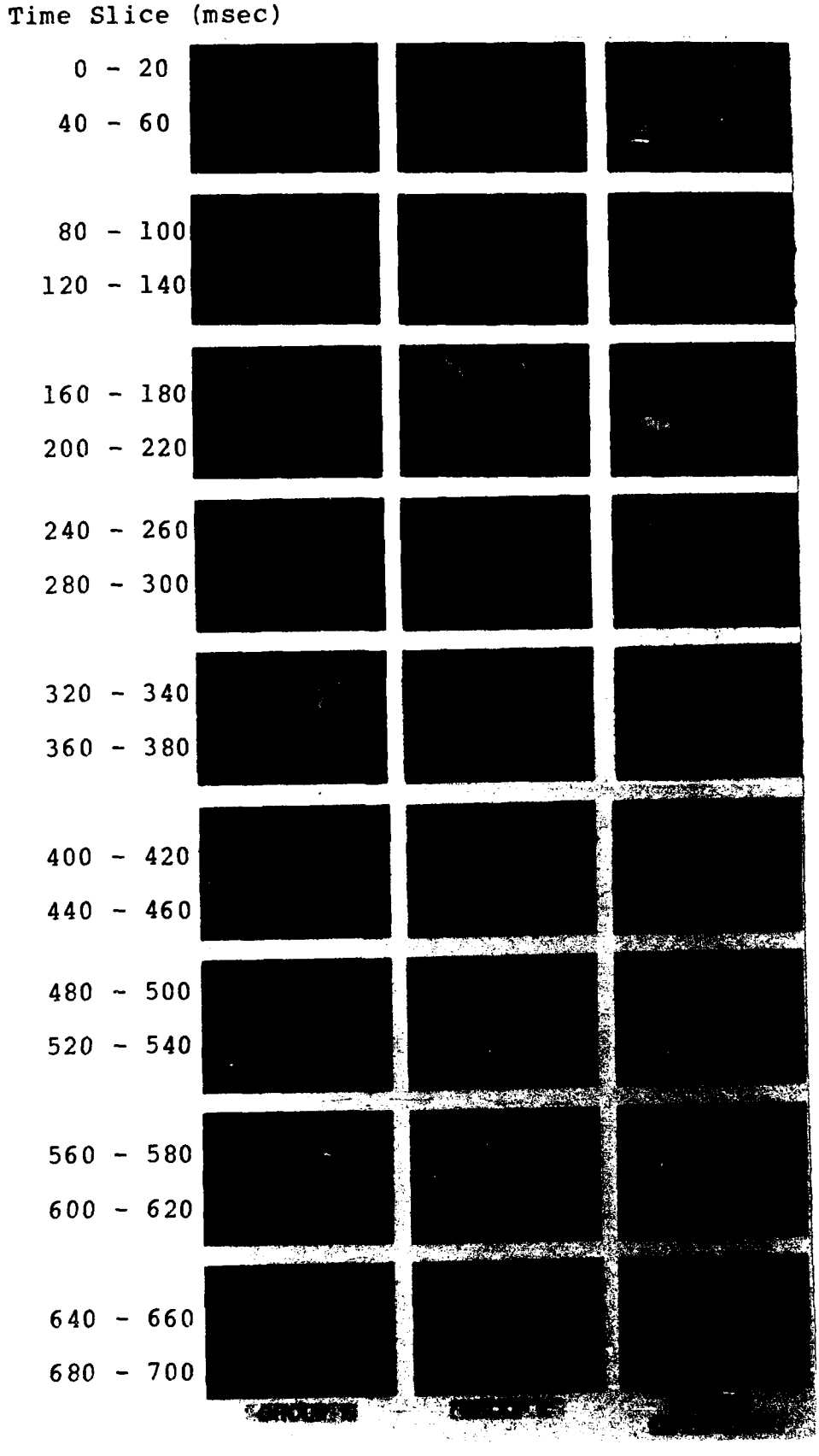


Figure 20. Group Data: Memory Set 1, Positive Set, Trial 1.

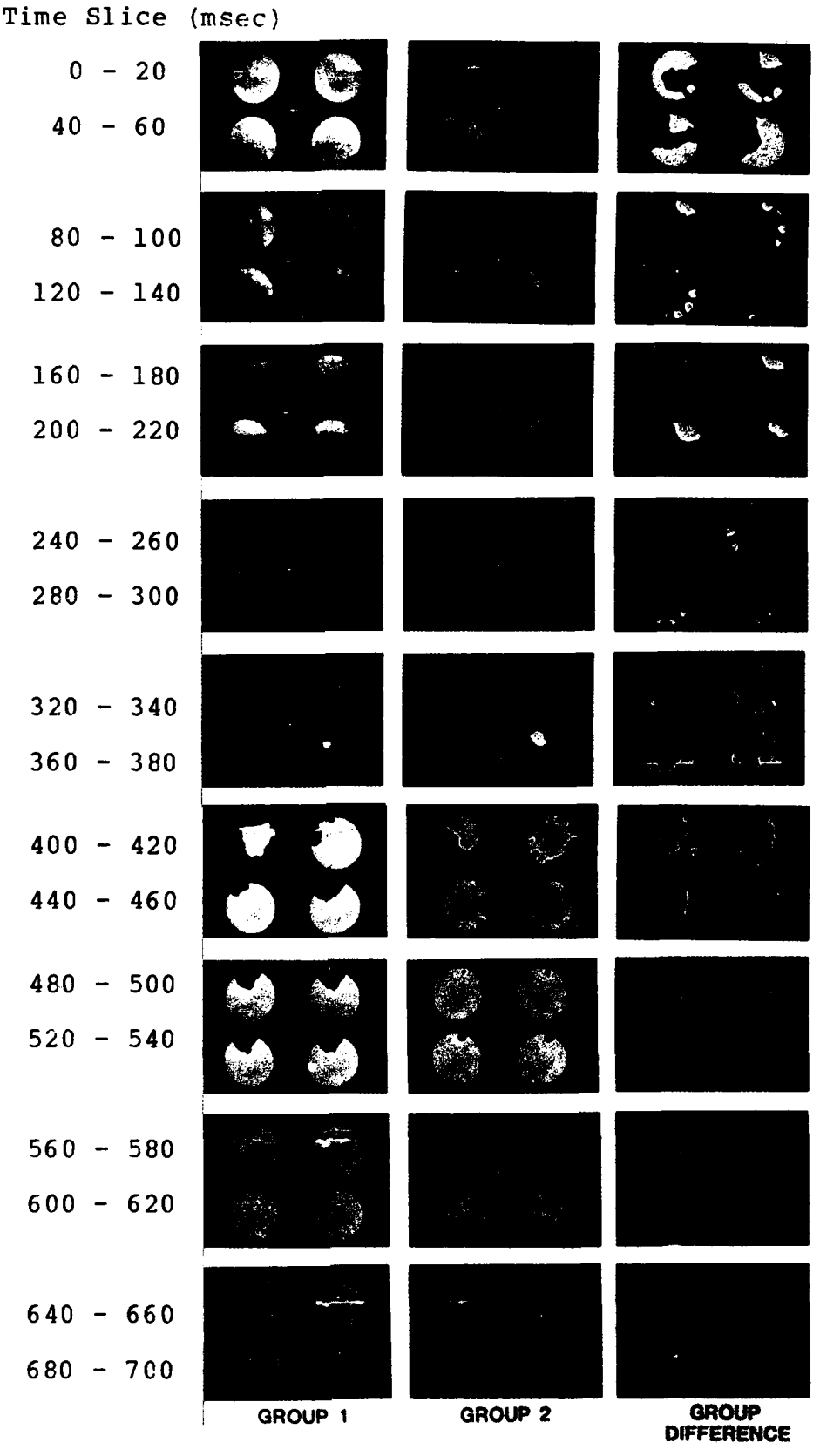


Figure 21. Group Data: Memory Set 1, Negative Set, Trial 1.

demonstrate the possibility of the use of ERPs as valid predictors of performance on cognitive tasks. Figures 31 through 33 contain the topomaps for group differences for trial 10. It appears that as experience is gained with the task, the LPC component differences become more important, especially at the lower memory set sizes. Overall, these results are encouraging and should be pursued in further research.

5. Psychometric Data

The means for the personality tests were well within a range that is typical of a normal population (Figure Psy D). The average IQ, as already noted, was in the superior range. Although we related the psychometric data to the ERP and performance data, these results are not presented because of the small N. One result is interesting and that is the relationship of impulsiveness to the group differences in RT performance. The three subjects with the fastest RTs had the lowest BIS-10 total scores while the three subjects with the slowest RTs had the highest BIS-10 scores. This is consistent with past research results but with a small sample, these results are not always obtained. Anxiety did

			$\bar{x}$	Range
Slosson IQ			138	120-157
EPQ	Psychotic		3.4	0-6
	Extraversion		15.0	10-19
	Neurotic		7.4	3-15
	Lie		7.6	2-12
BIS-10	I Cognitive		10.2	8-31
	I Motor		12.9	4-21
	I Non-planning		19.1	4-31
STPI	State	Anxiety	14.3	10-26
		Anger	10.0	10-10
	Trait	Anxiety	18.1	14-24
		Anger	16.1	11-29
G-2. Spatial Orientation			25.1	10-43
Embedded Figures			15.7	11-18

Figure Psy. D. - Psychometric Data.

not relate to performance scores which is interesting from the standpoint of "arousal" theory. There have been suggestions that anxiety and brain stem "arousal" are related to RT scores. If they are, these results would be important in the interpretation of the ERP data.

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THE SPECIFICITY OF N400 TO SEMANTIC MISMATCHES

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The Specificity of N400 to Semantic Mismatches.

An attempt was made to determine the specificity of the N400 component of the event-related protential (ERP) to semantic "mismatch" information processing. ERP recordings were made from Fz, Cz, and Pz (left earlobe reference; forehead ground; high frequency cut-off 35 Hz; 5 s time constant). The electroculogram (EOG) deflections in excess of 30 uv were excluded from further analysis. Fifteen male subjects were run using two structurally equivalent versions of the oddball task, one semantic (75% exemplars from category BIRD versus 25% exemplars from category FRUIT) and one physical (75% the character array XXXXX versus 25% the character array XKXXX, XXKXX, or XXXKX occuring with equal frequency). The exemplars in each semantic category had equivalent average lengths (5.2 characters) and Rosch typicality ratings. Subjects made reaction time button presses in response to both the frequent and infrequent stimuli; the frequent stimuli required a "match" response while the infrequent stimuli required a "mismatch" response.

The two tasks were designed so that in each the amplitude and latency of the late positive complex (LPC), which is subsequent to N400 and partially overlapping with it, would be similar. This was done in an attempt to avoid confounding semantic versus physical mismatch effects on the amplitude and/or latency of the LPC.

The ERP components of interest were measured as follows: based upon inspection of the superaverage waveforms, N200 was defined as the average amplitude (100 ms prestimulus baseline-

referenced) in the epoch 200-325 ms, N400 was defined as the average amplitude in the epoch 325-450 ms, and the LPC was defined as the average amplitude in the epoch 450-575 ms. LPC latency (maximum positivity) was also measured in the 450-575 ms epoch as well as in a wider 300-700 ms epoch. Analysis of variance results indicated significant N400 activity at all three loci was associated with semantic but not physical mismatches. Although LPC latency did not differ as a function of semantic versus physical mismatches, LPC amplitude did, with the semantic mismatch LPC being smaller; further, correlations between semantic minus physical mismath amplitudes indicated that the significant semantic mismatch N400 effect was independent of corresponding LPC effects only at Pz. A significant semantic versus physical mismatch effect was obtained for the earlier N200 wave at Fz, but this was not independent of the LPC. Reaction time data indicated matches were significantly faster than mismatches for both the semantic and physical conditions. It is concluded that N400 may be uniquely associated with semantic mismatch information processing at posterior areas of the scalp, while N200 probably is not; further, N400 does not appear to be a delayed instance of the N200 component.

As a follow-up, a second study was intitiated to evaluate laterality of the N400 component. ERP recordings were made from FP1, FP2, F7, F8, F3, F4, Fz, T3, T4, C3, C4, Cz, T5, T6, P3, P4, Pz, O1, and O2 (nasal reference); otherwise, the testing pradigm and data analysis were as outlined above. Preliminary results indicate that the N400 is greater over the right than the left

hemishpere at central and parietal but not frontal and occipital leads. Additional analyses using color-coded topographic mapping techniques will be performed.